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(54) **SYSTEMS AND METHODS FOR SPECTRAL IMAGING WITH COMPENSATION FUNCTIONS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(22) Filed: **Feb. 3, 2020**

(65) **Prior Publication Data**

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Related U.S. Application Data

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(60) Provisional application No. 62/444,731, filed on Jan. 10, 2017.

(51) **Int. Cl.**

H04N 5/225	(2006.01)
G06K 9/32	(2006.01)
G06K 9/20	(2006.01)

(52) **U.S. Cl.**

CPC ***H04N 5/2256*** (2013.01); ***G06K 9/2027*** (2013.01); ***G06K 9/3233*** (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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Primary Examiner — Talha M Nawaz

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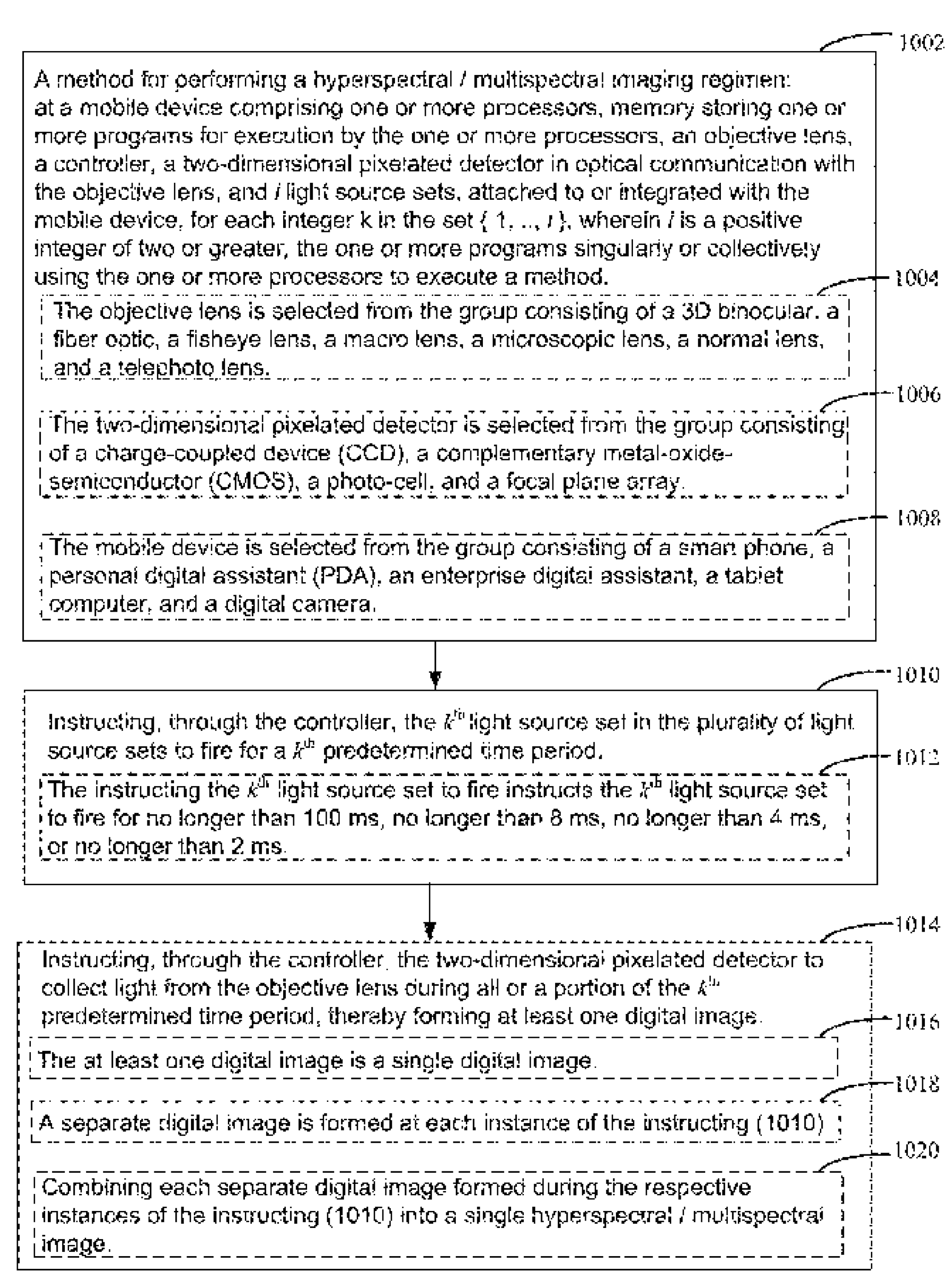
(57) **ABSTRACT**

Provided are systems and methods for imaging with compensation functions. An imaging device comprises a plurality of light source sets, of which two or more light source sets emit light of a same specific spectral range to compensate intensity differences among different spectral ranges. The imaging device can be integrated with a mobile device. A method comprises a subtraction procedure to compensate ambient light effect, a normalization procedure to compensate incidence angle effect, a 3D reconstruction procedure to compensate distance effect, or any combination of these procedures. The method is performed at an imaging device comprising a controller. At least one program is non-transiently stored in the controller and executable by the controller.

20 Claims, 28 Drawing Sheets



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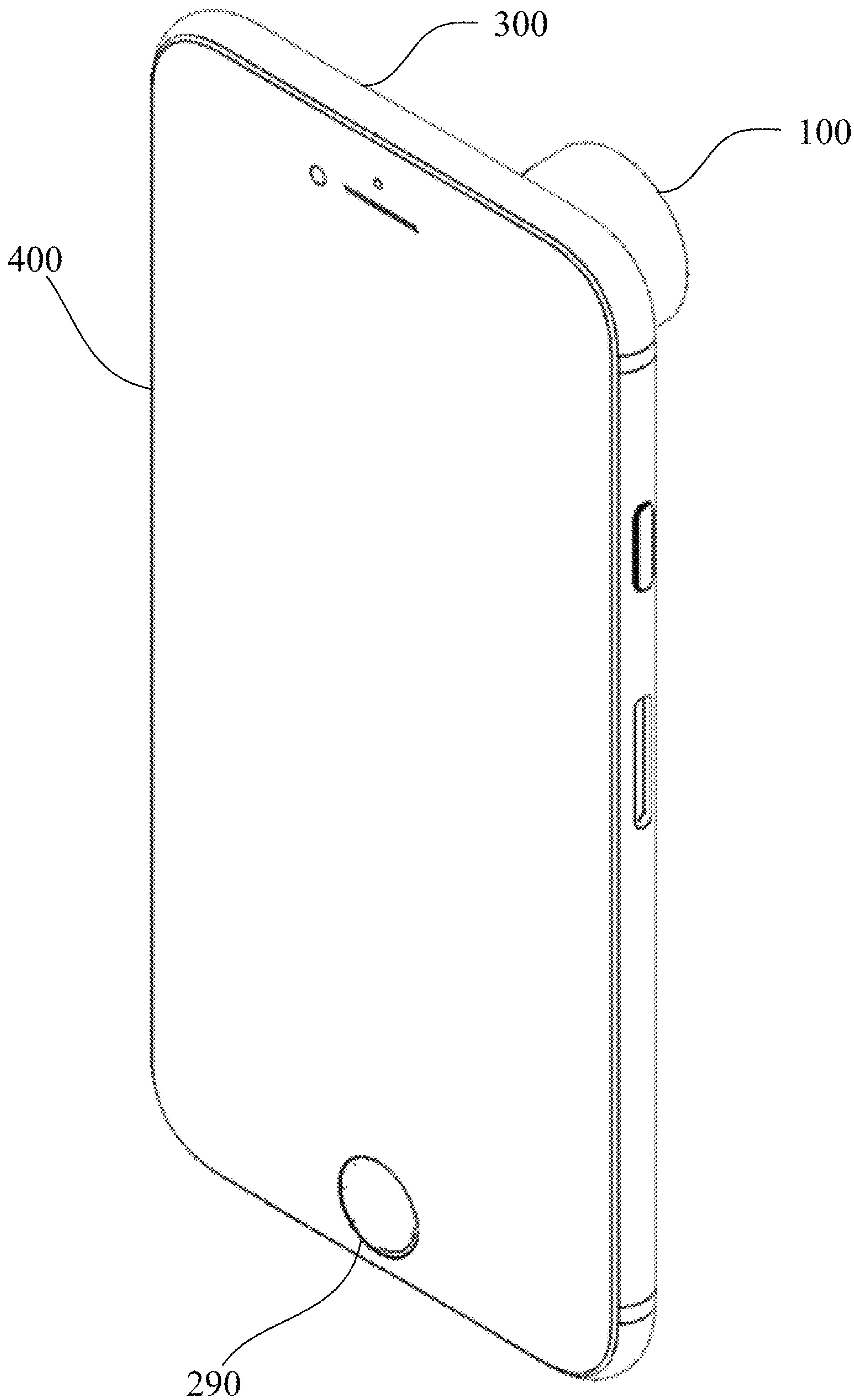
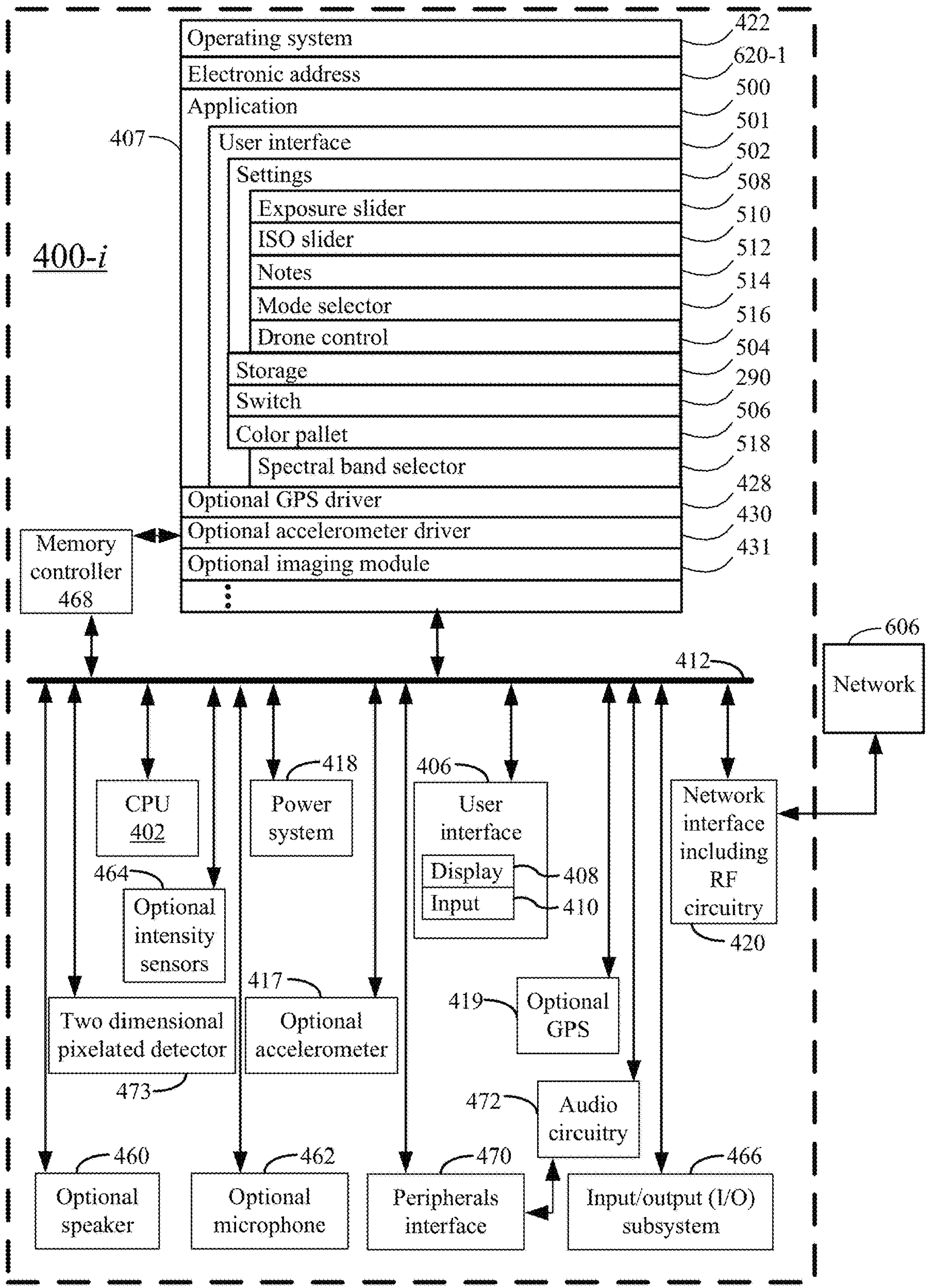


FIG. 1



400-i
Operating system
422
Electronic address
620-1
Application
500
User interface
501
Settings
502
Exposure slider
508
ISO slider
510
Notes
512
Mode selector
514
Drone control
516
Storage
504
Switch
290
Color pallet
506
Spectral band selector
518
Optional GPS driver
428
Optional accelerometer driver
430
Optional imaging module
431
407
Memory controller 468
412
606
Network
CPU 402
Power system
418
User interface
406
Display
408
Input
410
Network interface including RF circuitry
420
464
Optional intensity sensors
417
Optional accelerometer
Two dimensional pixelated detector
473
419
Optional GPS
472
Audio circuitry
460
Optional speaker
462
Optional microphone
470
Peripherals interface
466
Input/output (I/O) subsystem

FIG. 2

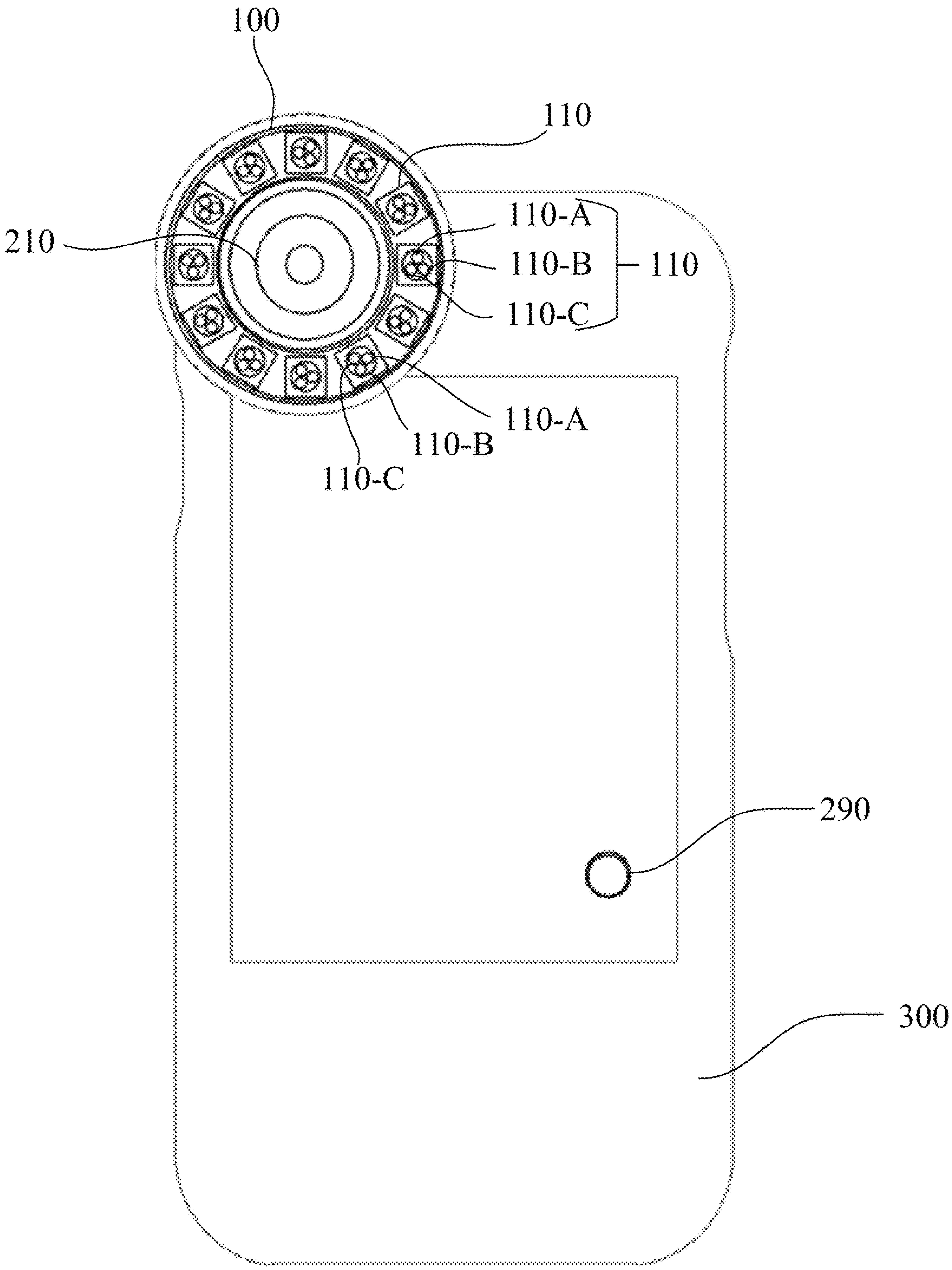


FIG. 3

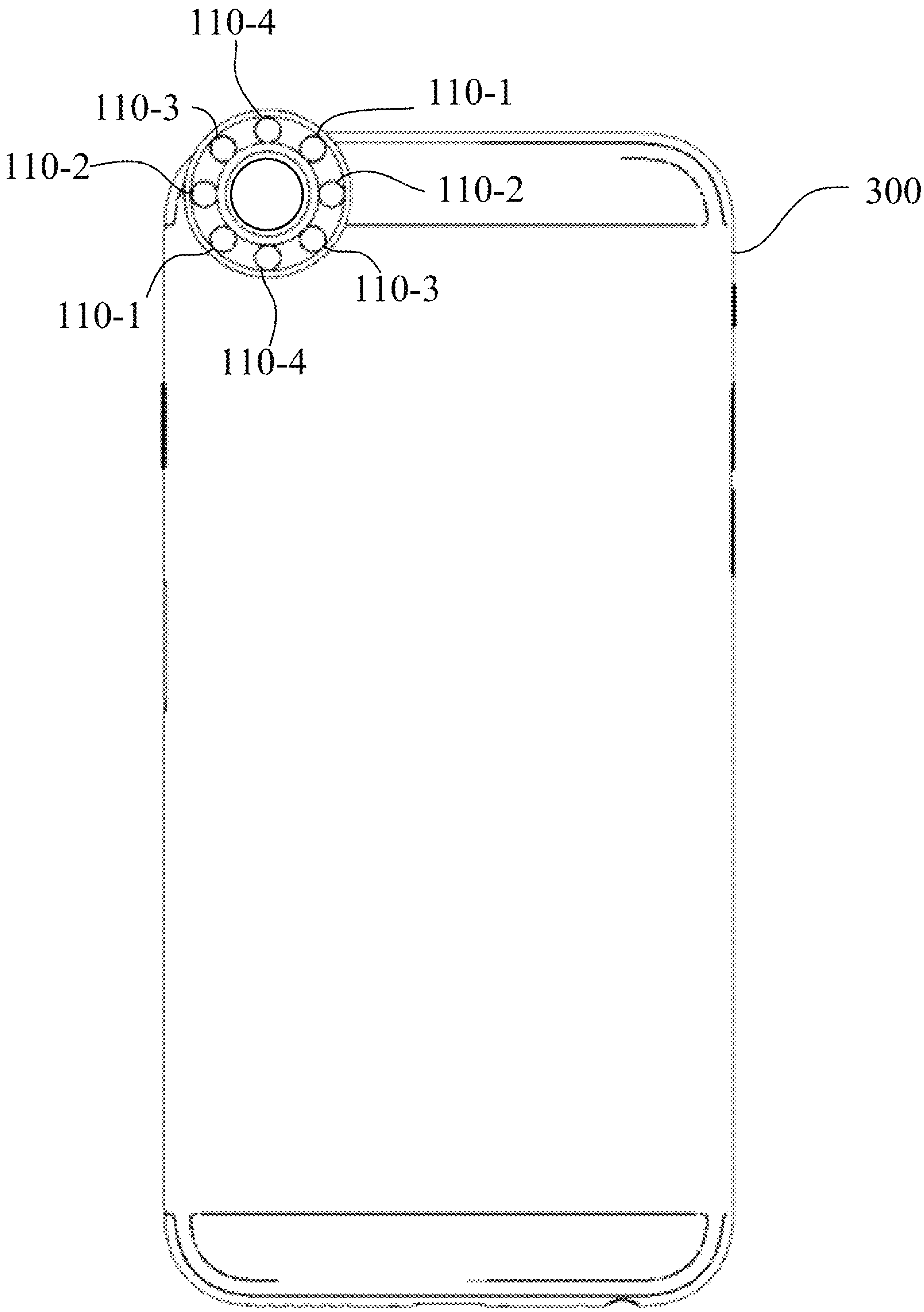


FIG. 4

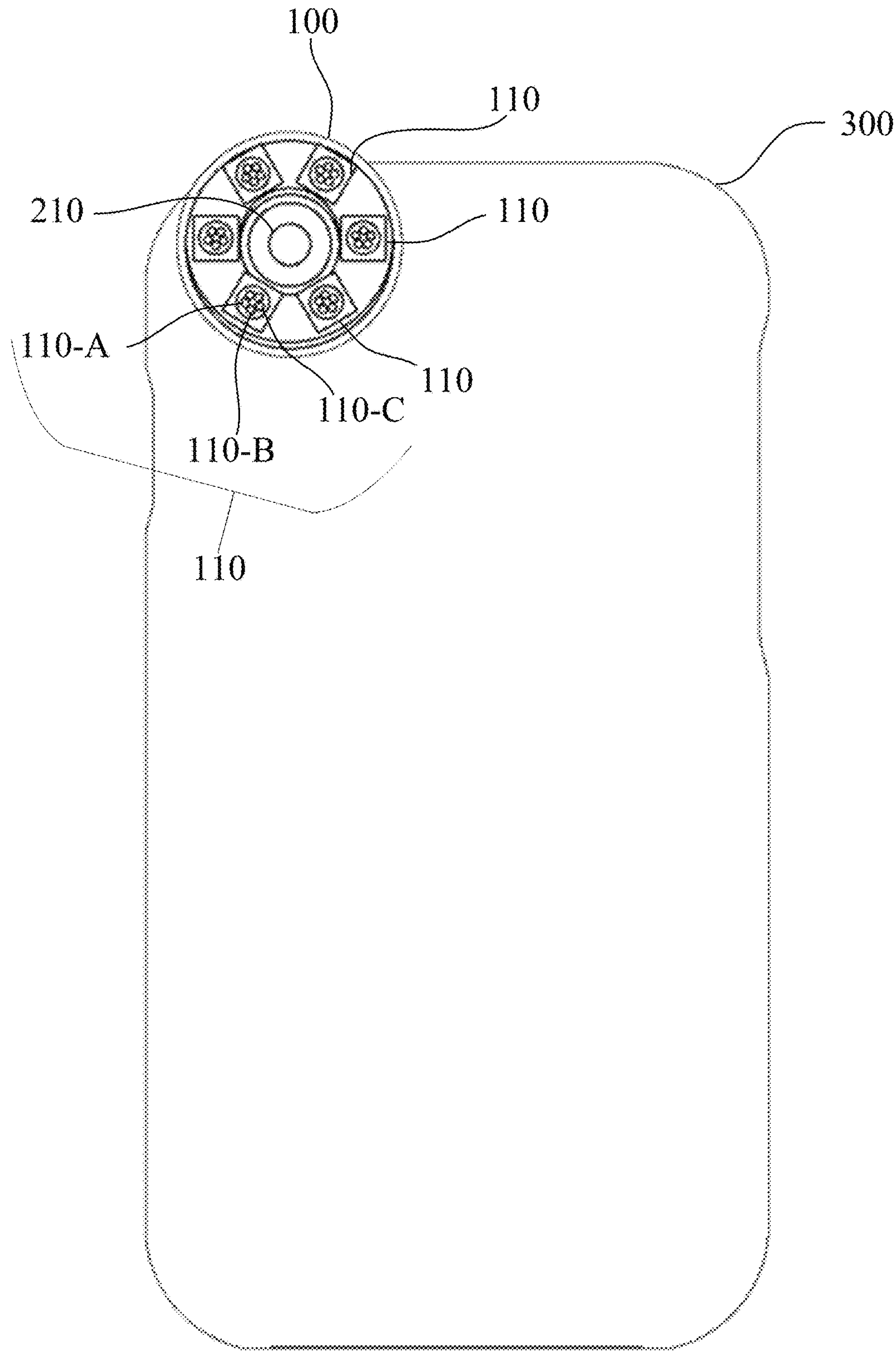


FIG. 5

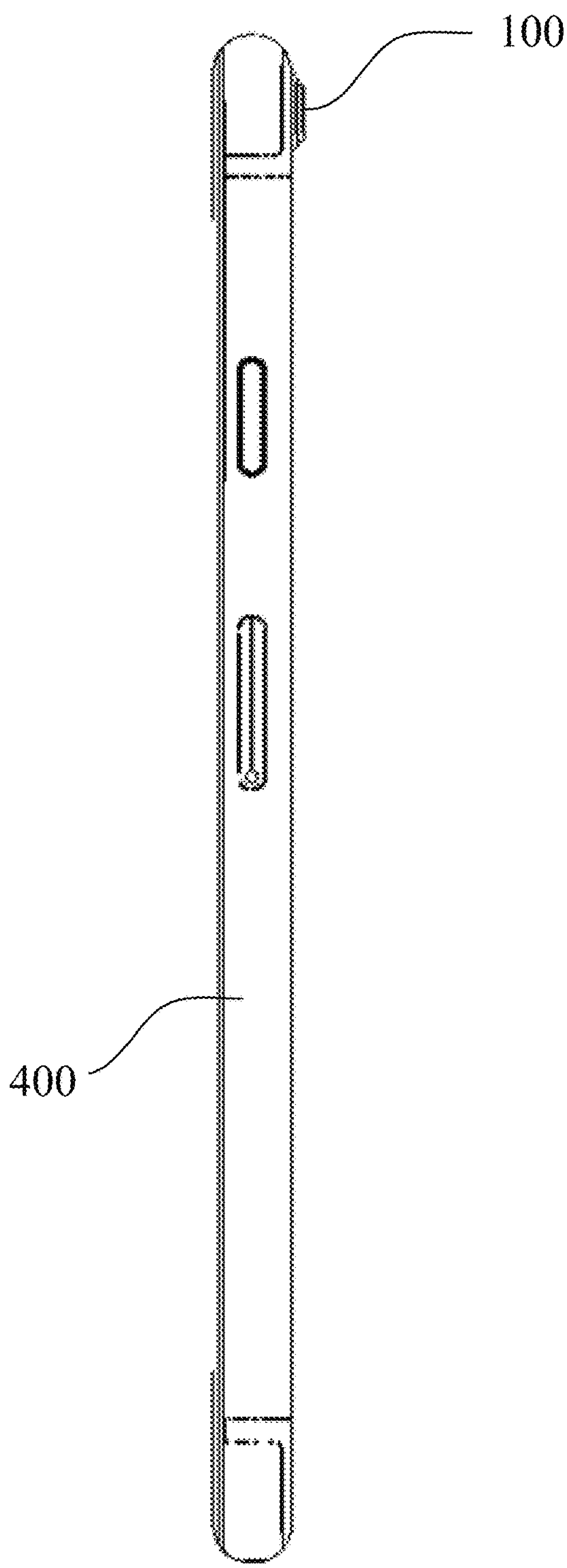


FIG. 6

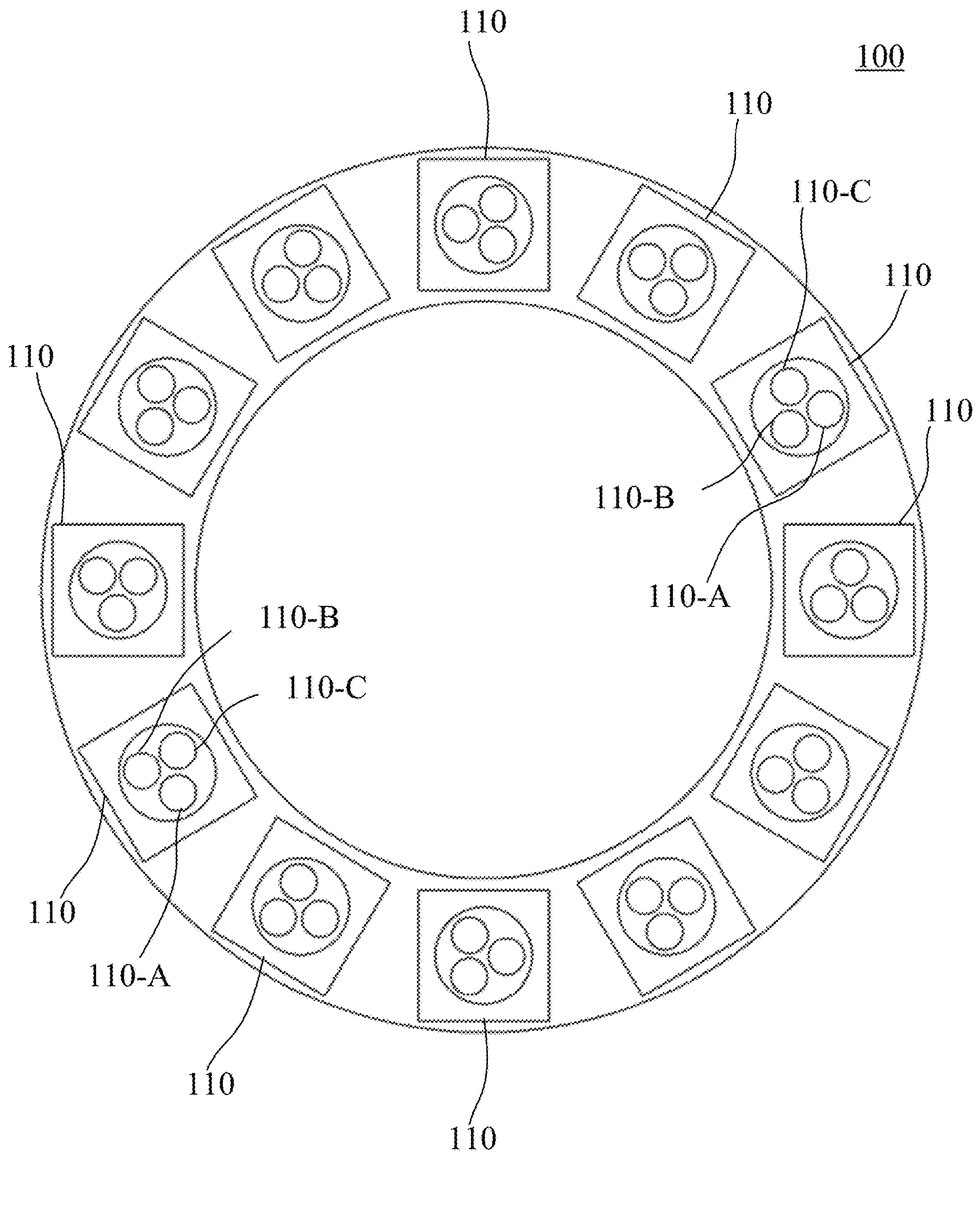
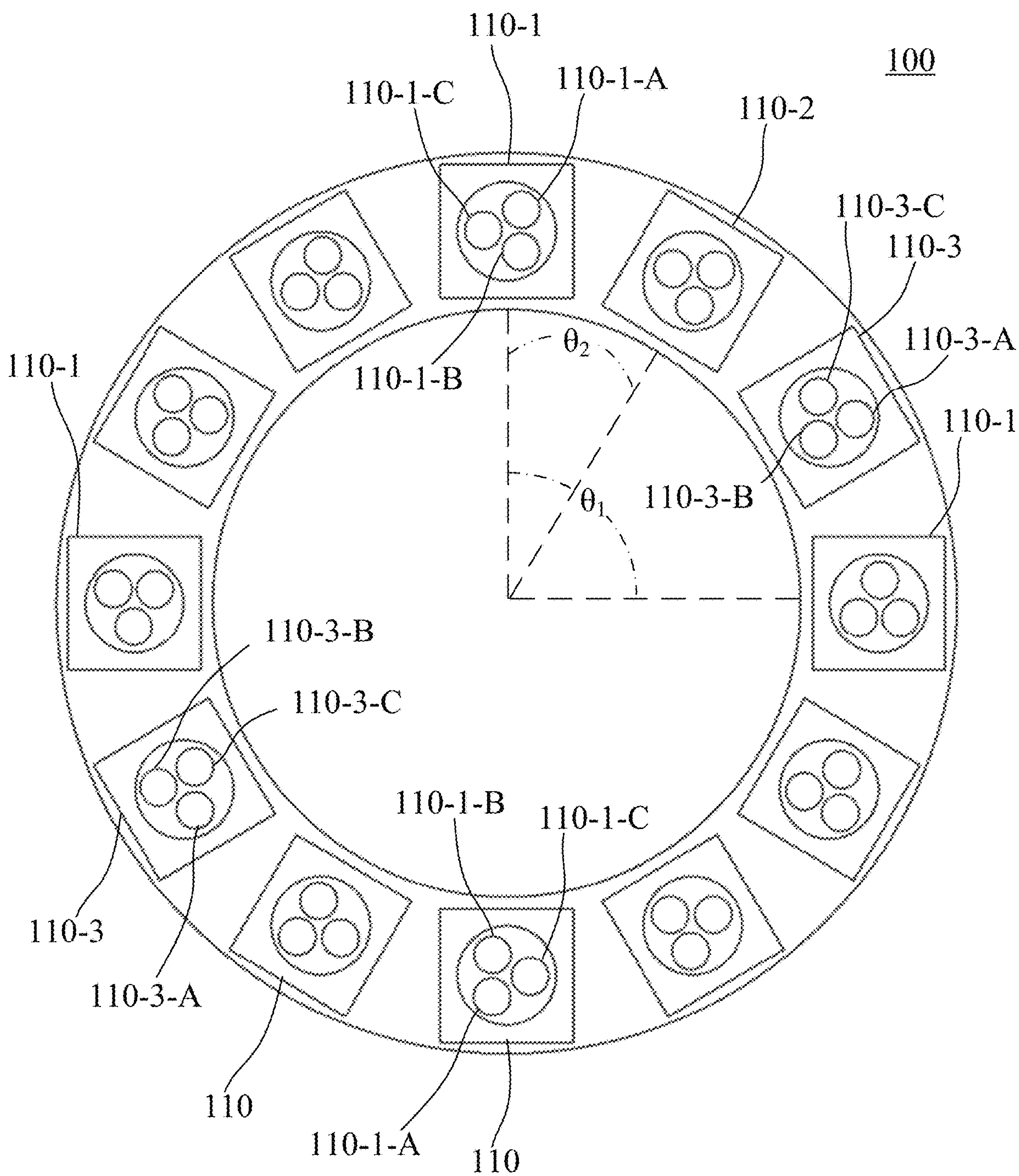

110
100
110
110-C
110
110
110
110-B
110
110-A
110-B
110-C
110
110-A
110
110

FIG. 7



100
110-1
110-1-C
110-1-A
110-2
110-3-C
110-3
110-3-A
110-1
110-1-B
θ_2
θ_1
110-3-B
110-1
110-3-B
110-3-C
110-1-B
110-1-C
110-3
110-3-A
110
110-1-A
110

FIG. 8

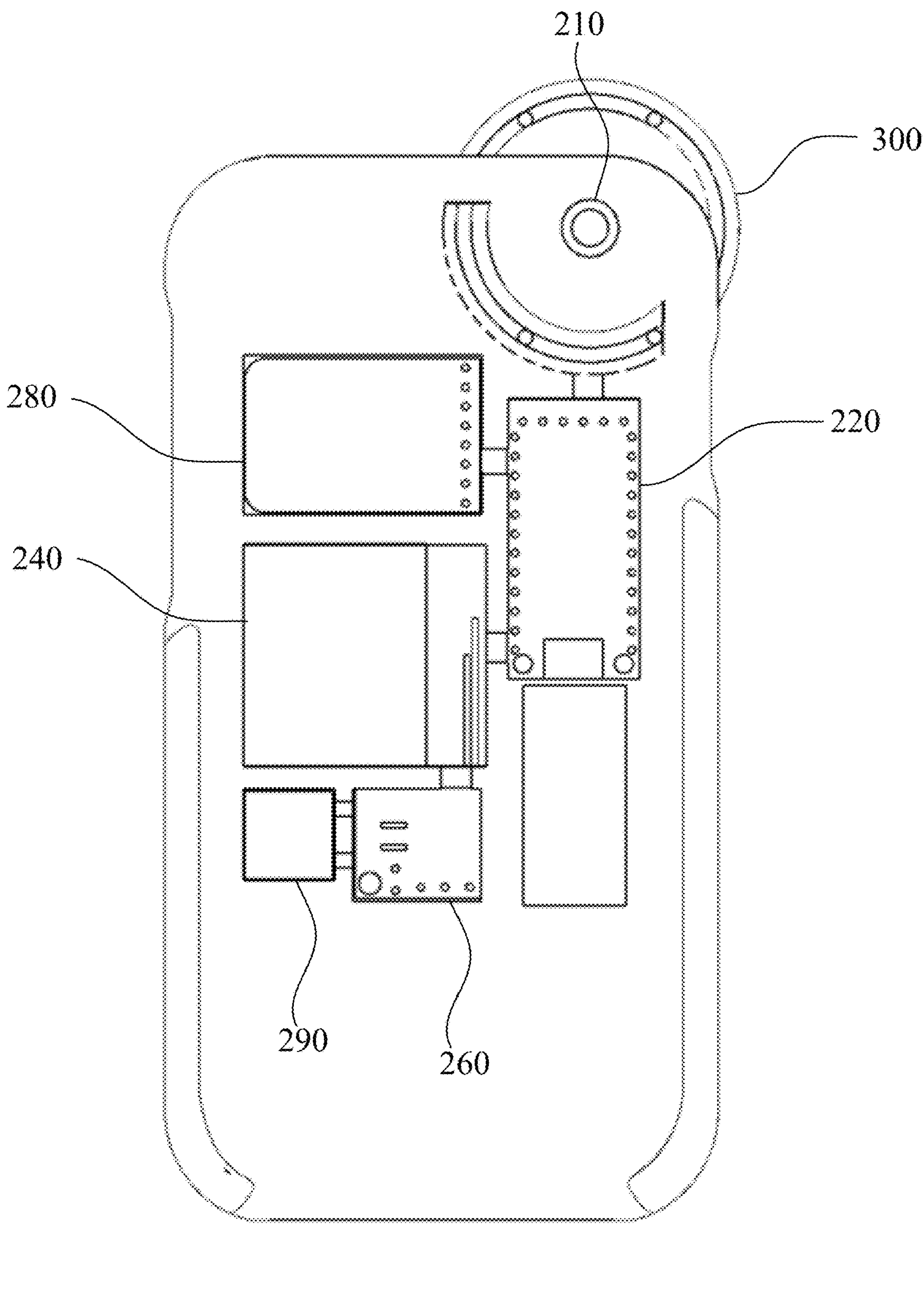


FIG. 9

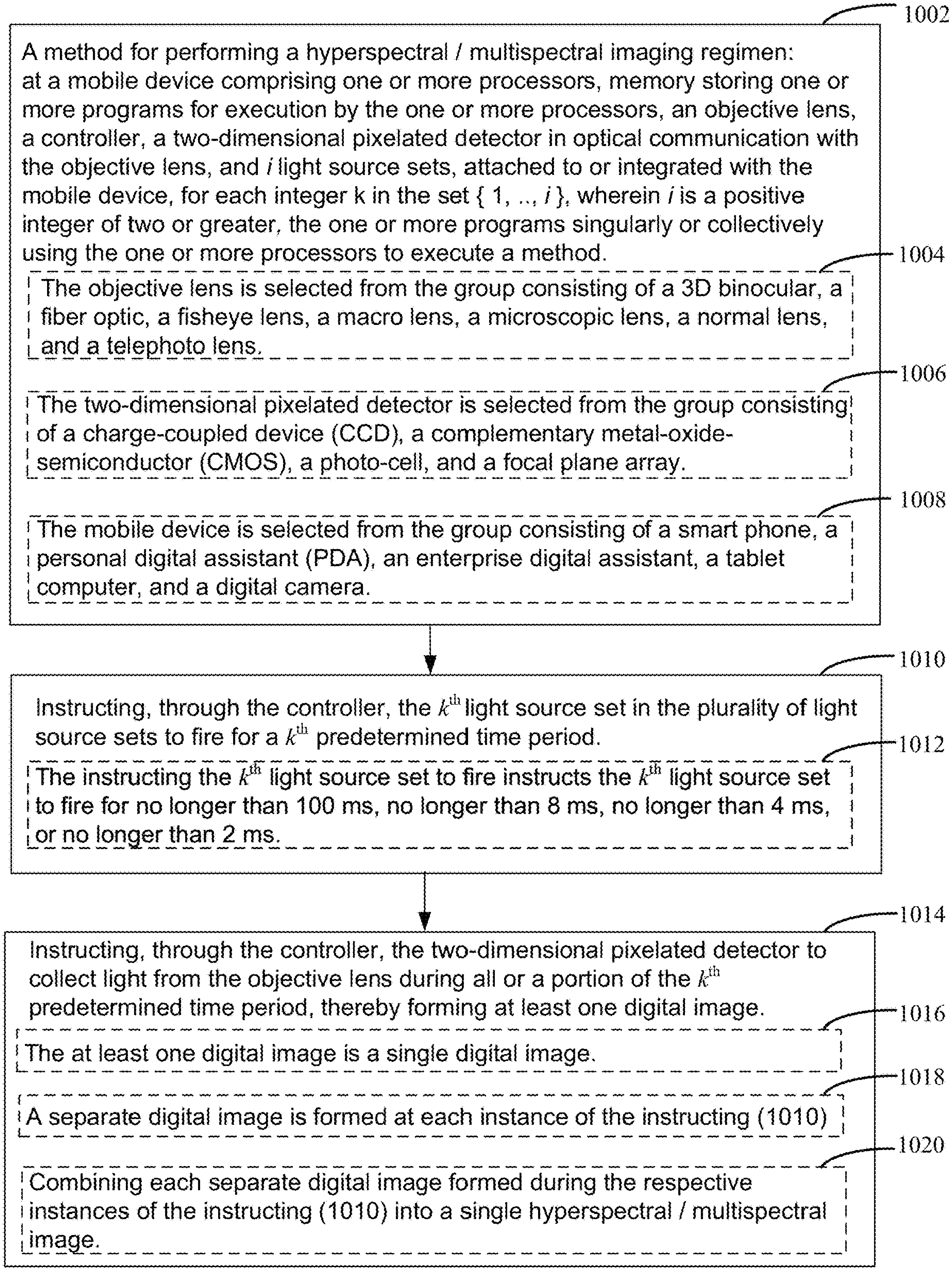

1002
A method for performing a hyperspectral / multispectral imaging regimen: at a mobile device comprising one or more processors, memory storing one or more programs for execution by the one or more processors, an objective lens, a controller, a two-dimensional pixelated detector in optical communication with the objective lens, and *i* light source sets, attached to or integrated with the mobile device, for each integer k in the set { 1, .., *i* }, wherein *i* is a positive integer of two or greater, the one or more programs singularly or collectively using the one or more processors to execute a method.
1004
The objective lens is selected from the group consisting of a 3D binocular, a fiber optic, a fisheye lens, a macro lens, a microscopic lens, a normal lens, and a telephoto lens.
1006
The two-dimensional pixelated detector is selected from the group consisting of a charge-coupled device (CCD), a complementary metal-oxide-semiconductor (CMOS), a photo-cell, and a focal plane array.
1008
The mobile device is selected from the group consisting of a smart phone, a personal digital assistant (PDA), an enterprise digital assistant, a tablet computer, and a digital camera.
1010
Instructing, through the controller, the k^{th} light source set in the plurality of light source sets to fire for a k^{th} predetermined time period.
1012
The instructing the k^{th} light source set to fire instructs the k^{th} light source set to fire for no longer than 100 ms, no longer than 8 ms, no longer than 4 ms, or no longer than 2 ms.
1014
Instructing, through the controller, the two-dimensional pixelated detector to collect light from the objective lens during all or a portion of the k^{th} predetermined time period, thereby forming at least one digital image.
1016
The at least one digital image is a single digital image.
1018
A separate digital image is formed at each instance of the instructing (1010)
1020
Combining each separate digital image formed during the respective instances of the instructing (1010) into a single hyperspectral / multispectral image.

FIG. 10

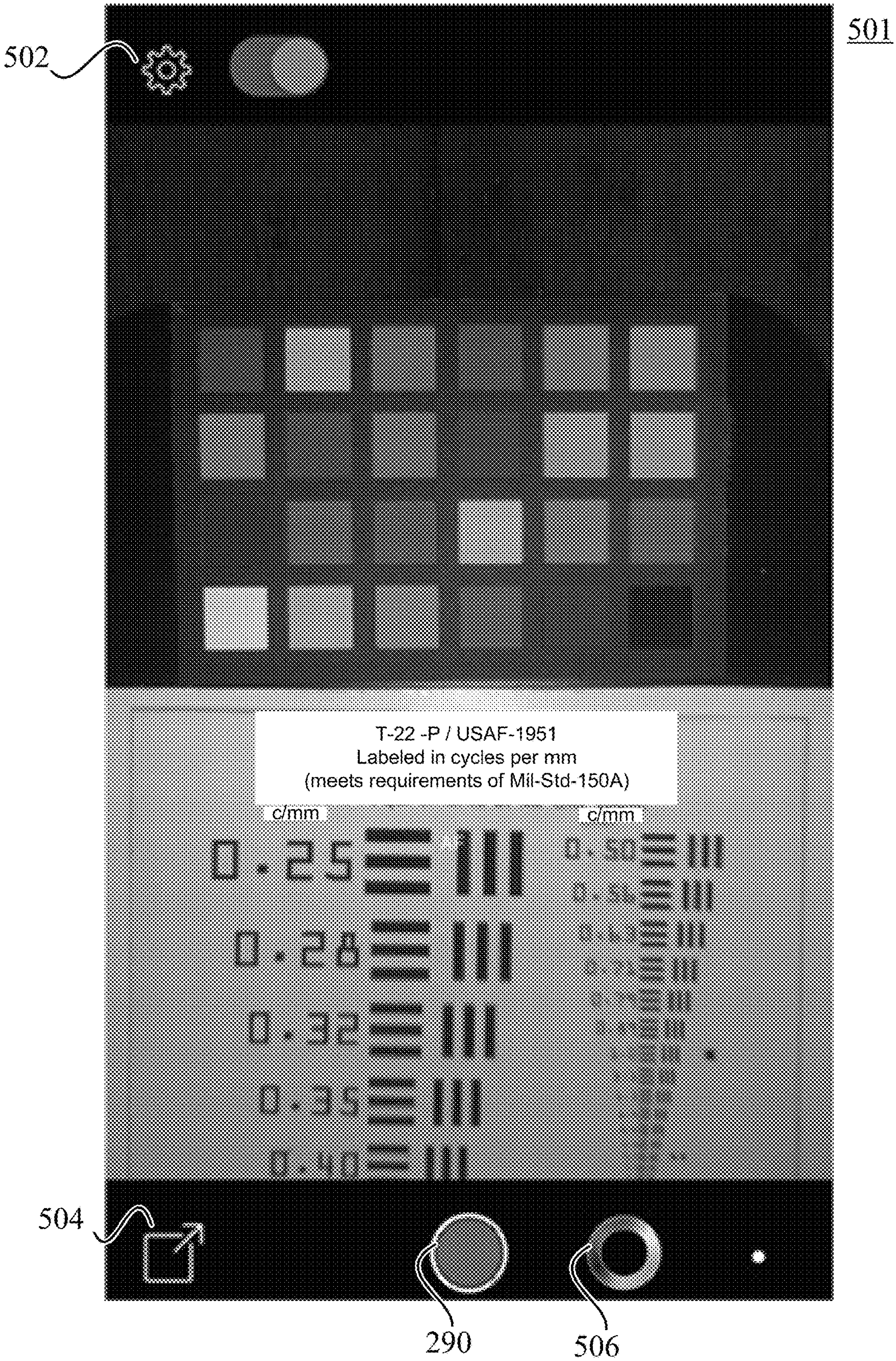

501
502
T-22 -P / USAF-1951
Labeled in cycles per mm
(meets requirements of Mil-Std-150A)
c/mm
c/mm
0.25
0.28
0.32
0.35
0.40
0.50
504
290
506

FIG. 11

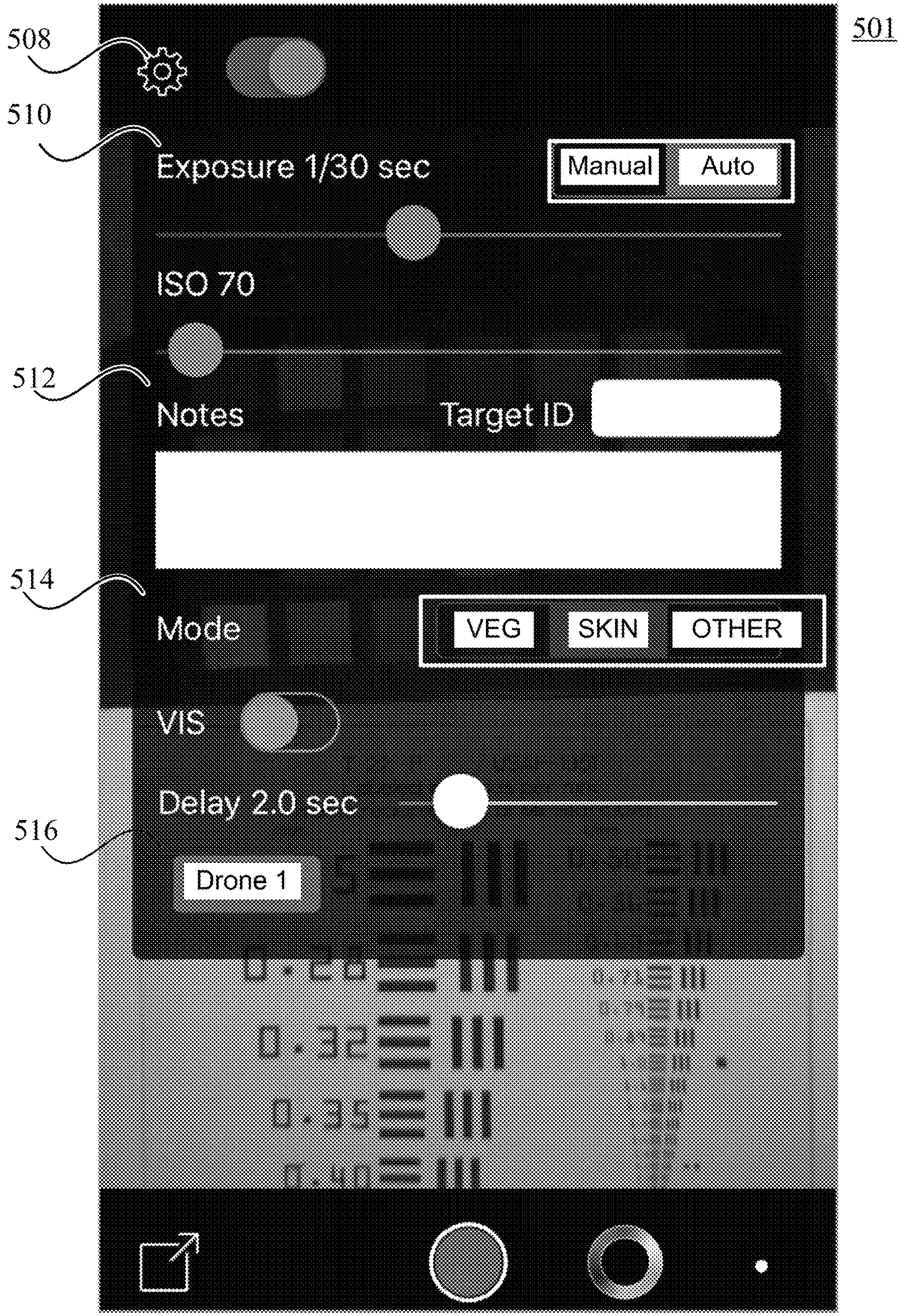

501
508
510
Exposure 1/30 sec
Manual
Auto
ISO 70
512
Notes
Target ID
514
Mode
VEG
SKIN
OTHER
VIS
Delay 2.0 sec
516
Drone 1
0.32
0.35

FIG. 12

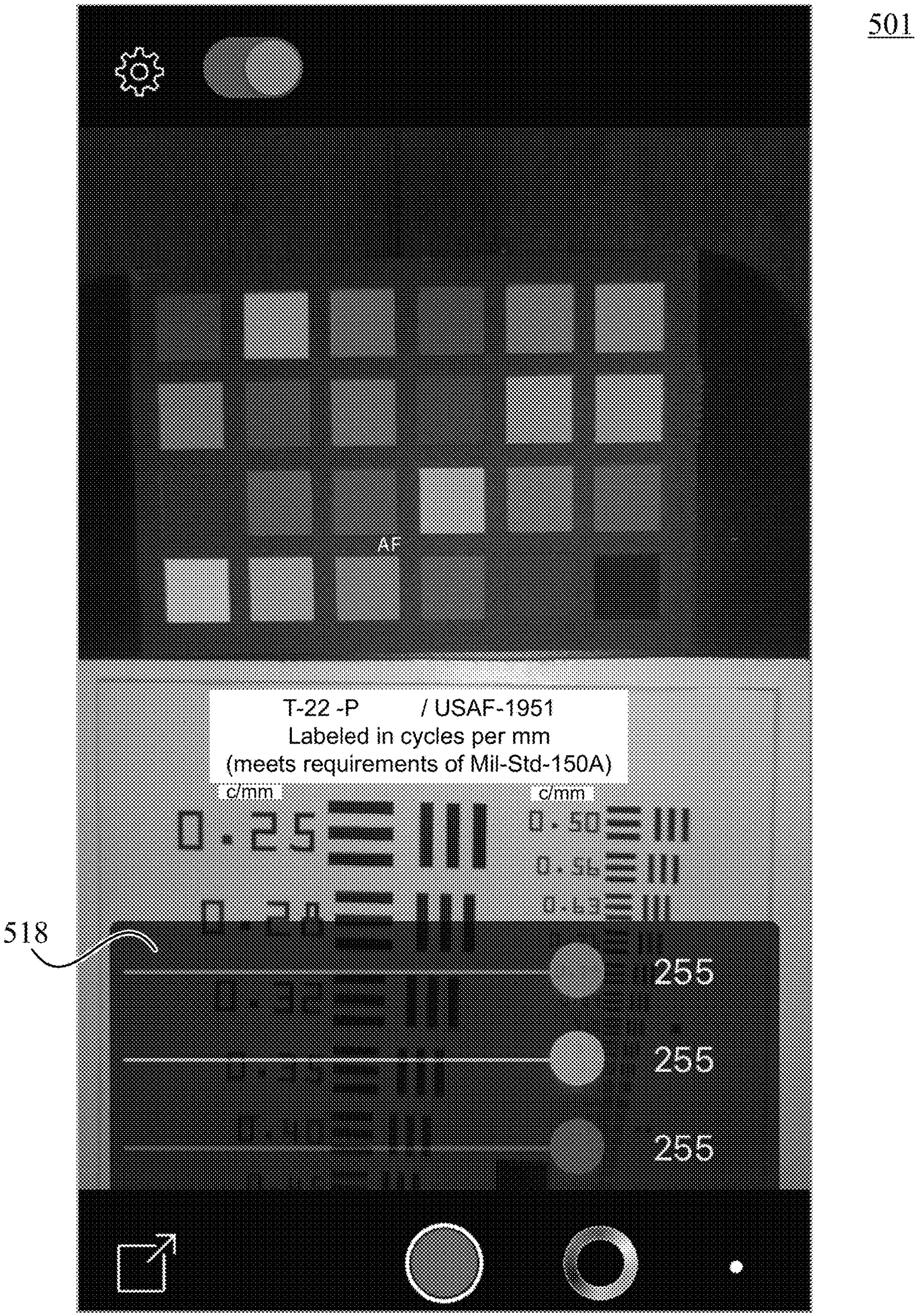

501
AF
T-22 -P / USAF-1951
Labeled in cycles per mm
(meets requirements of Mil-Std-150A)
c/mm
c/mm
0.25
0.50
518
255
255
255

FIG. 13

FIG. 14C

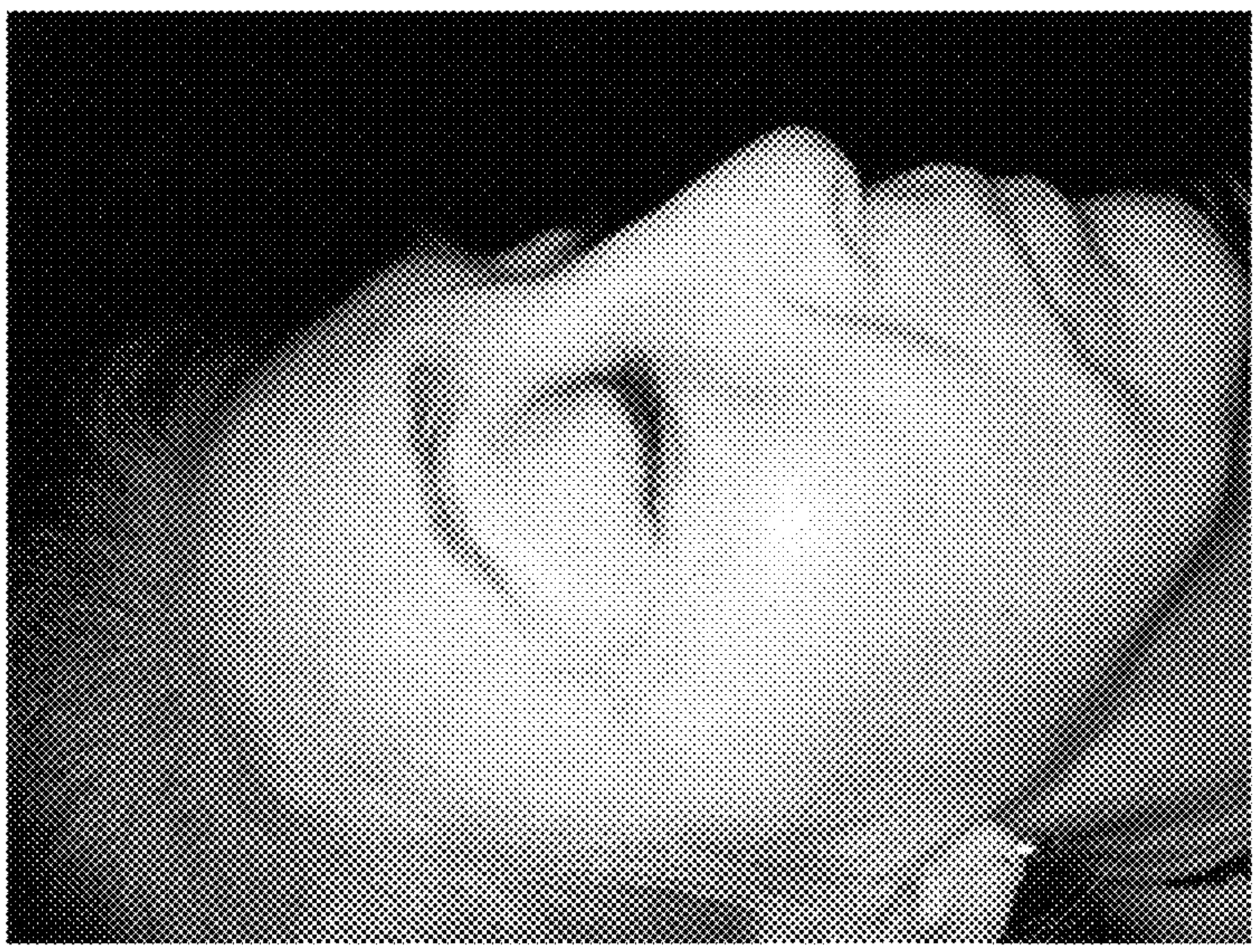


FIG. 14B

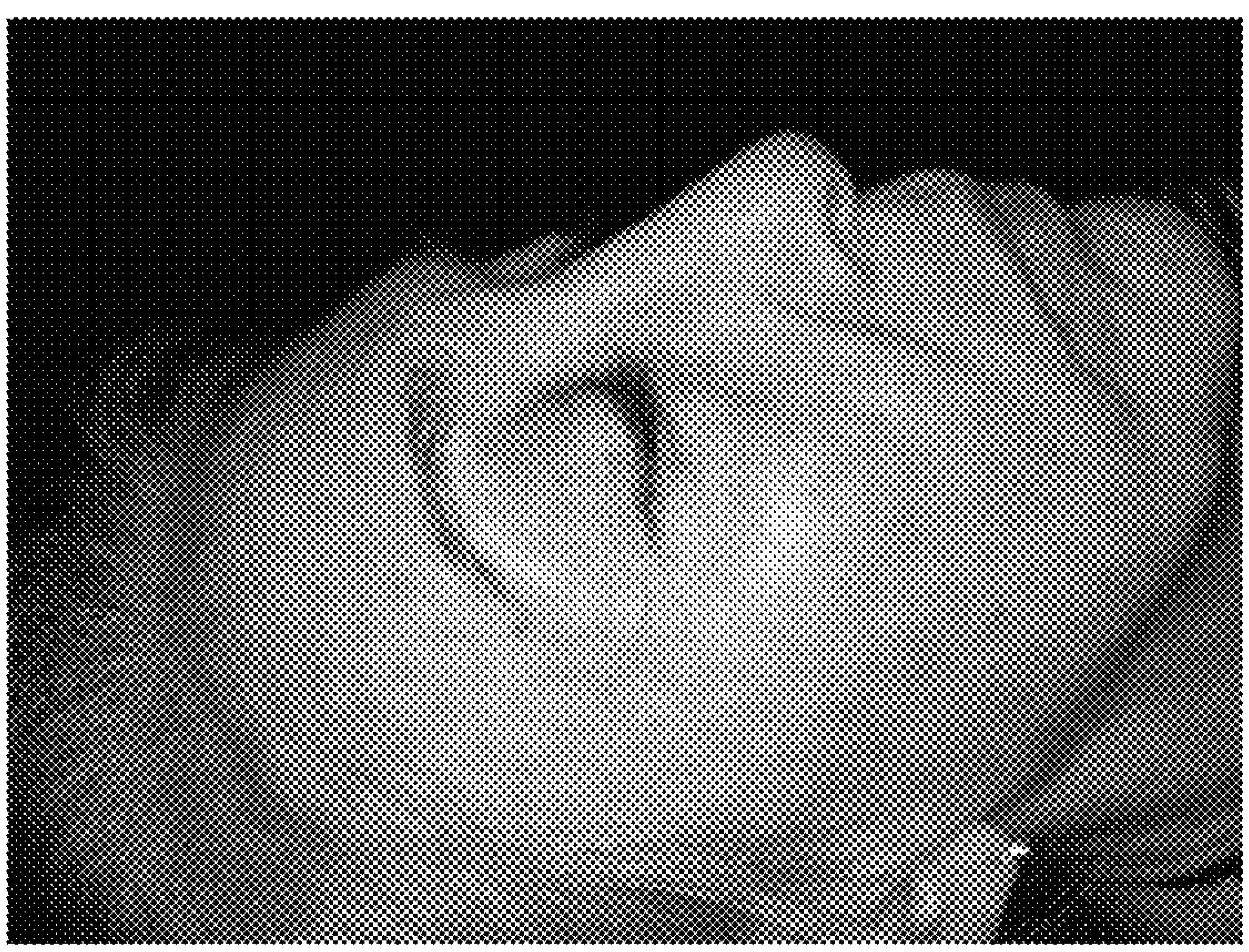


FIG. 14A

FIG. 14E

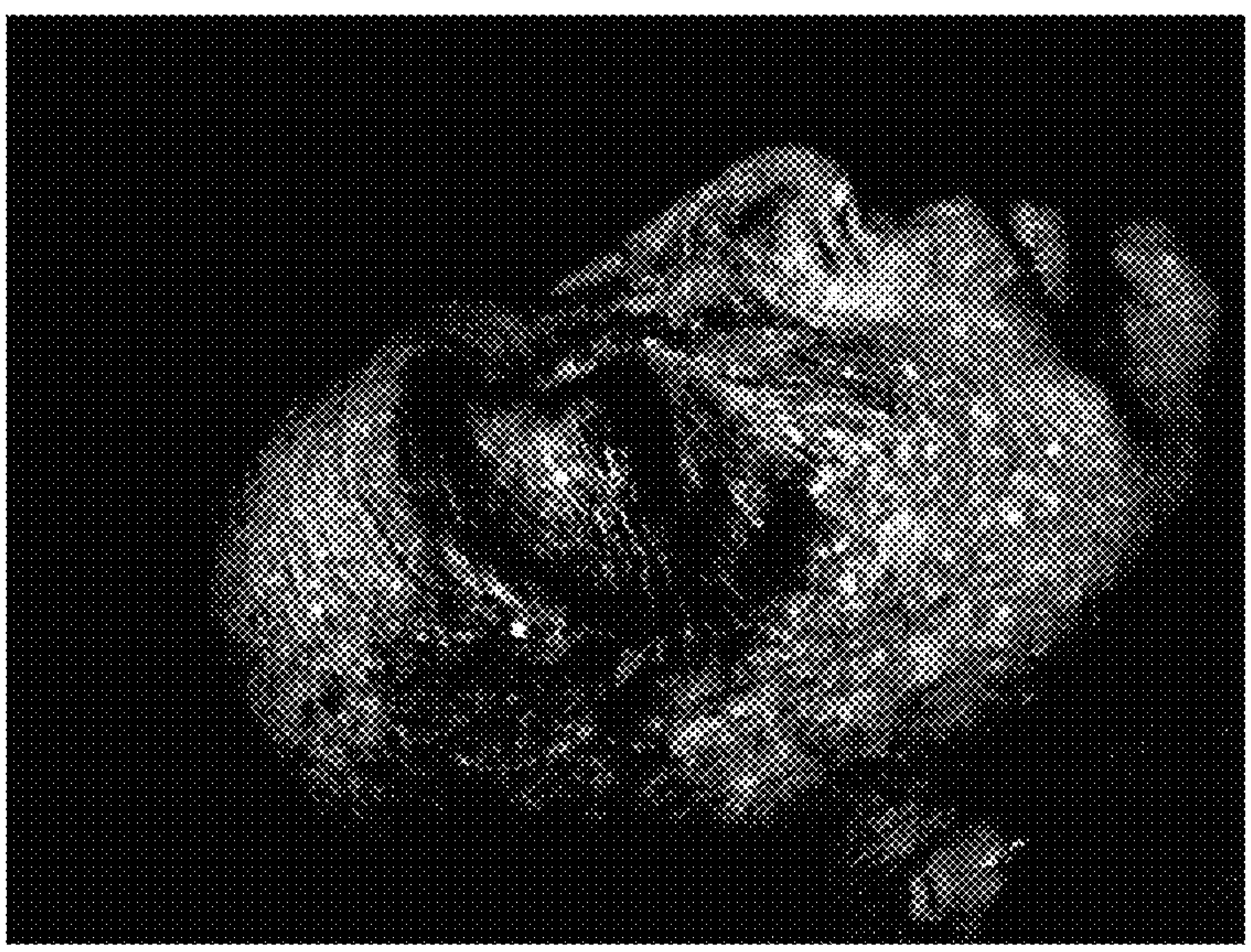


FIG. 14D

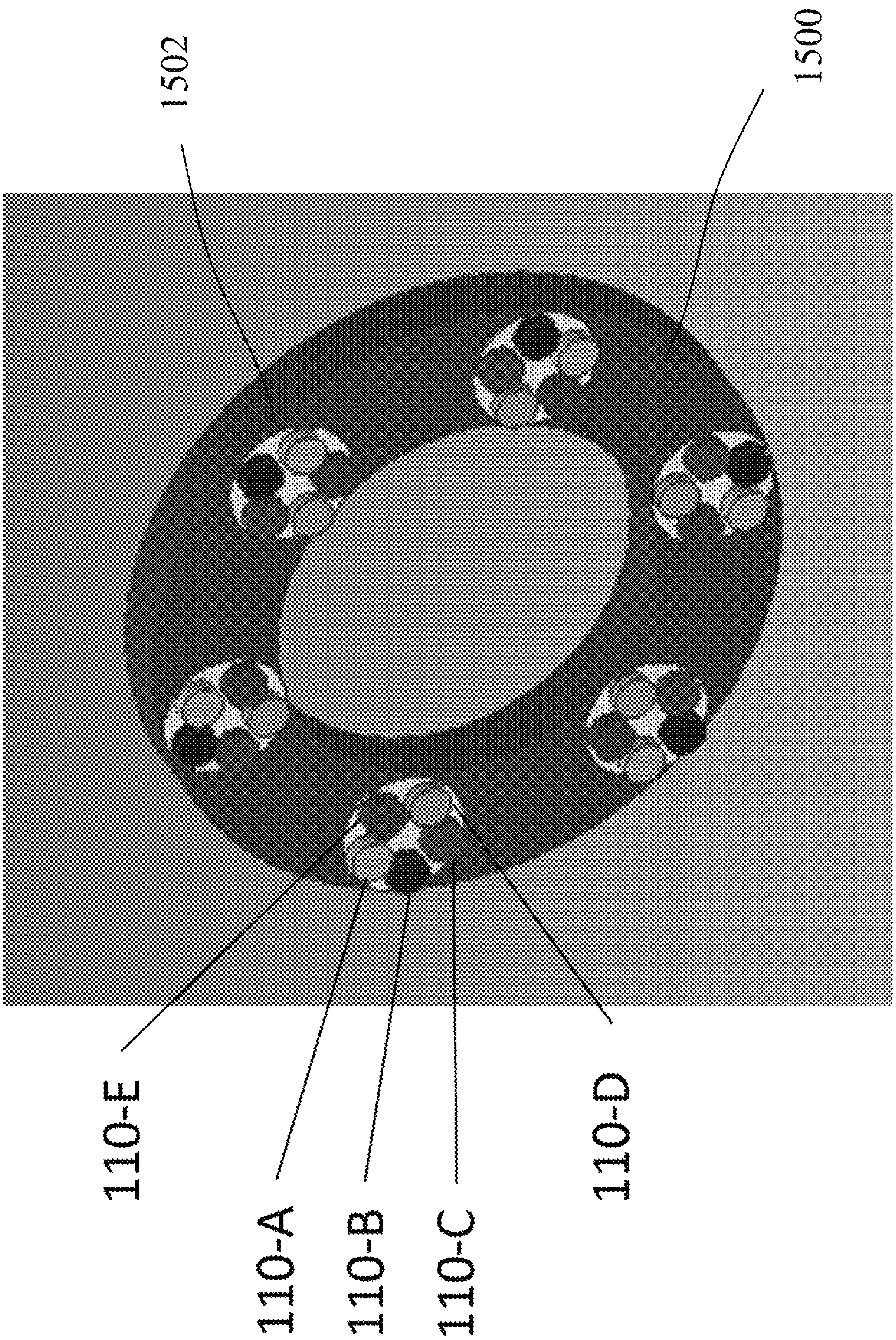


FIG. 15A

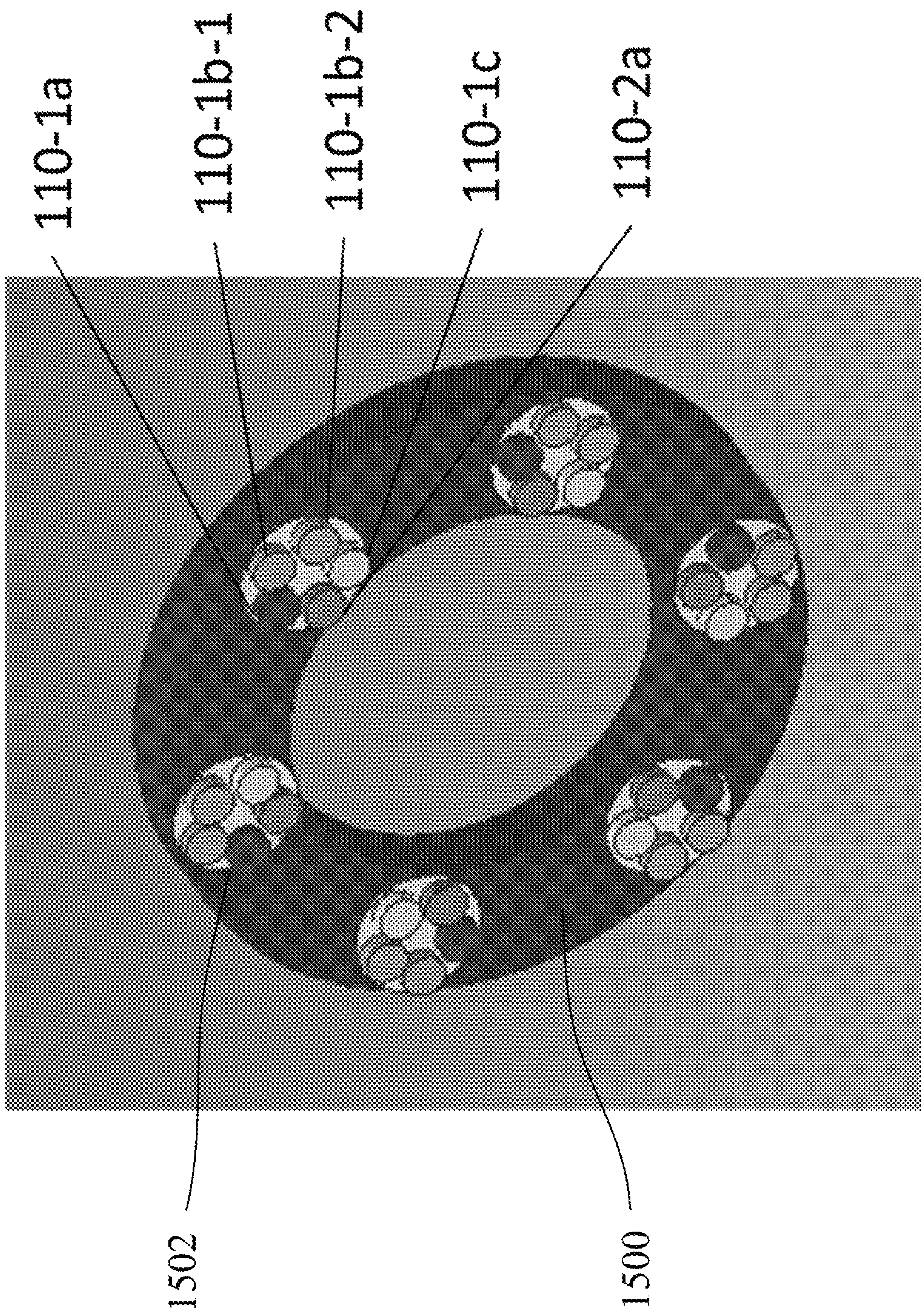


FIG. 15B

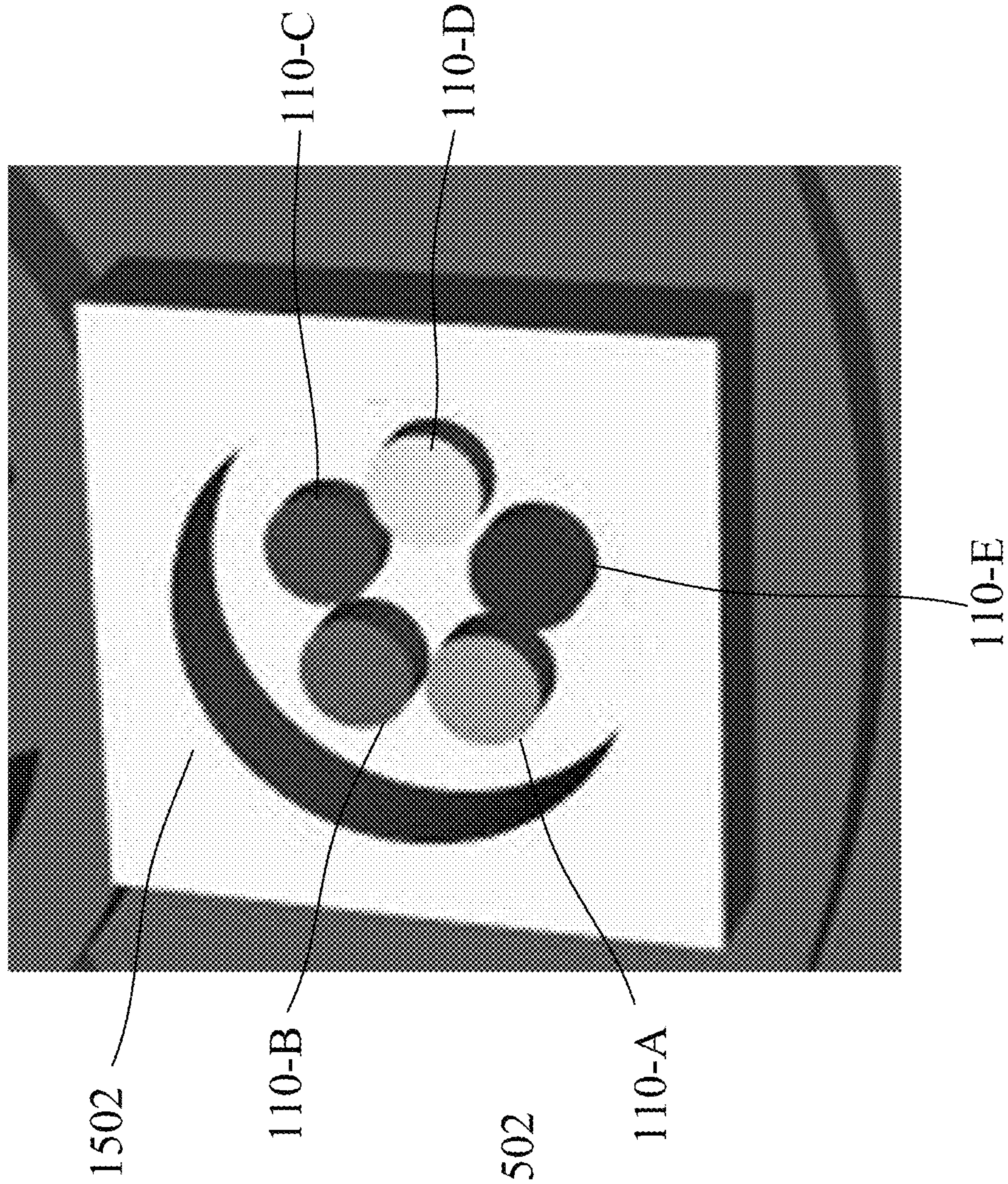


FIG. 15D

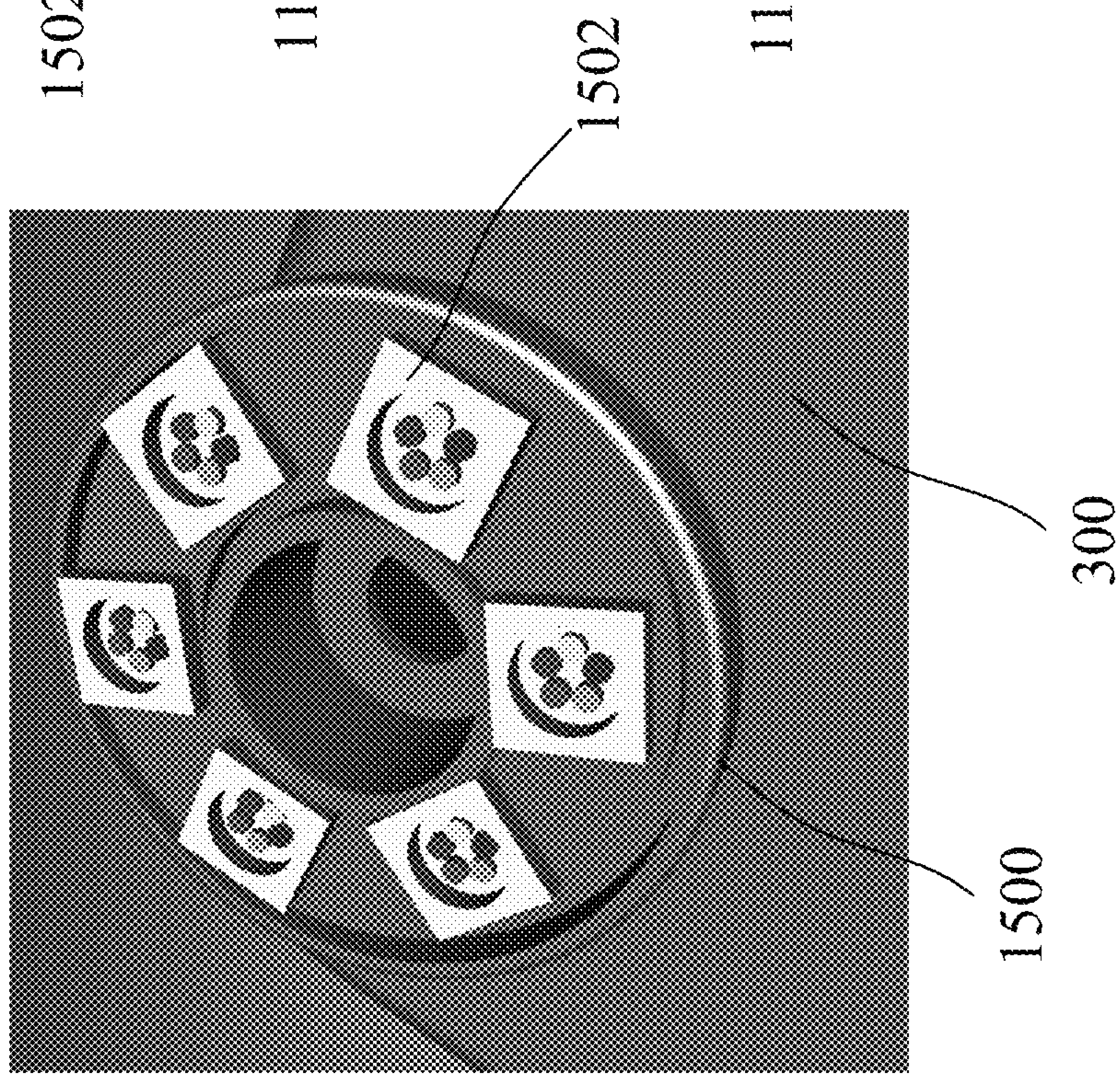


FIG. 15C

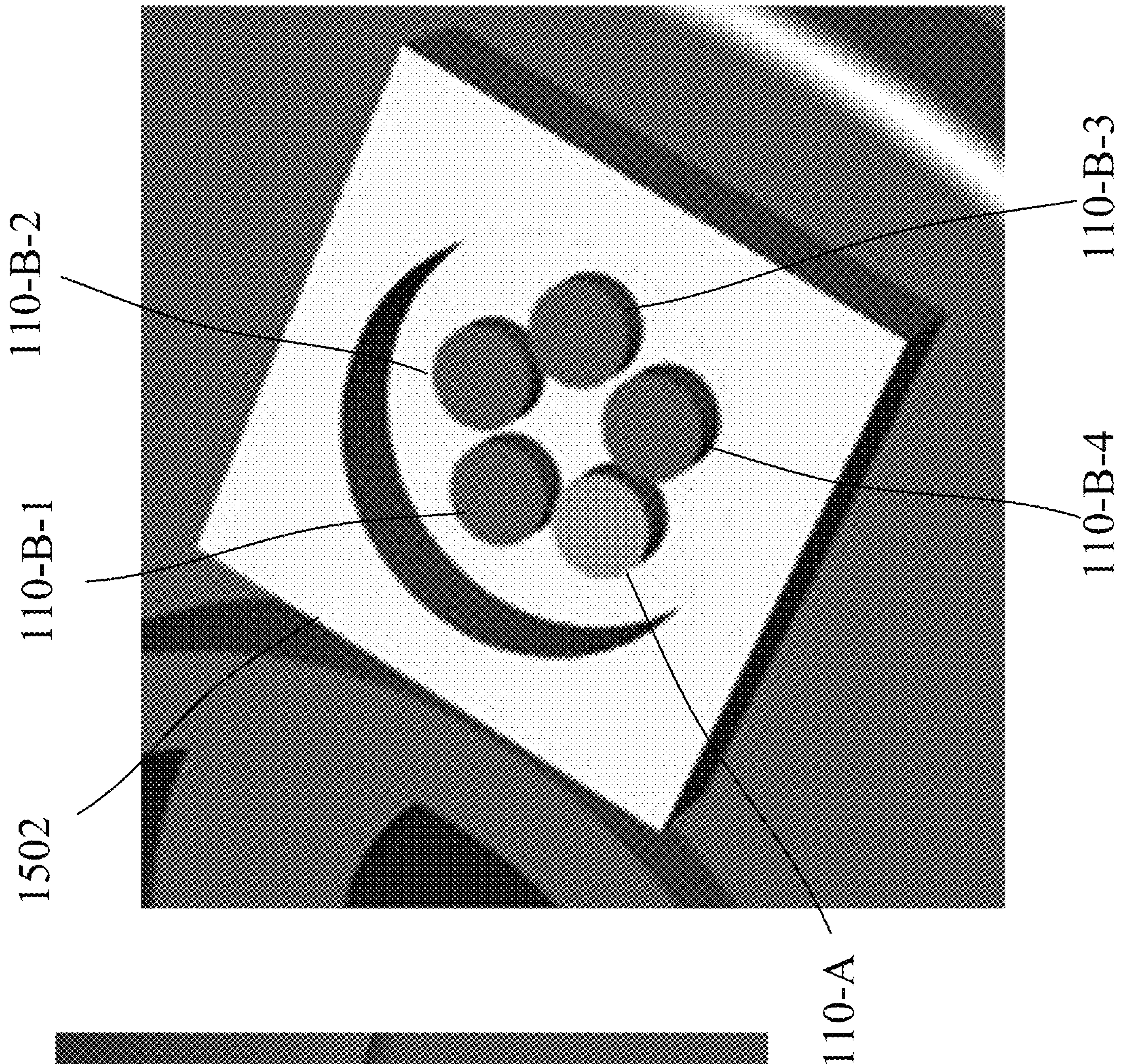


FIG. 15F

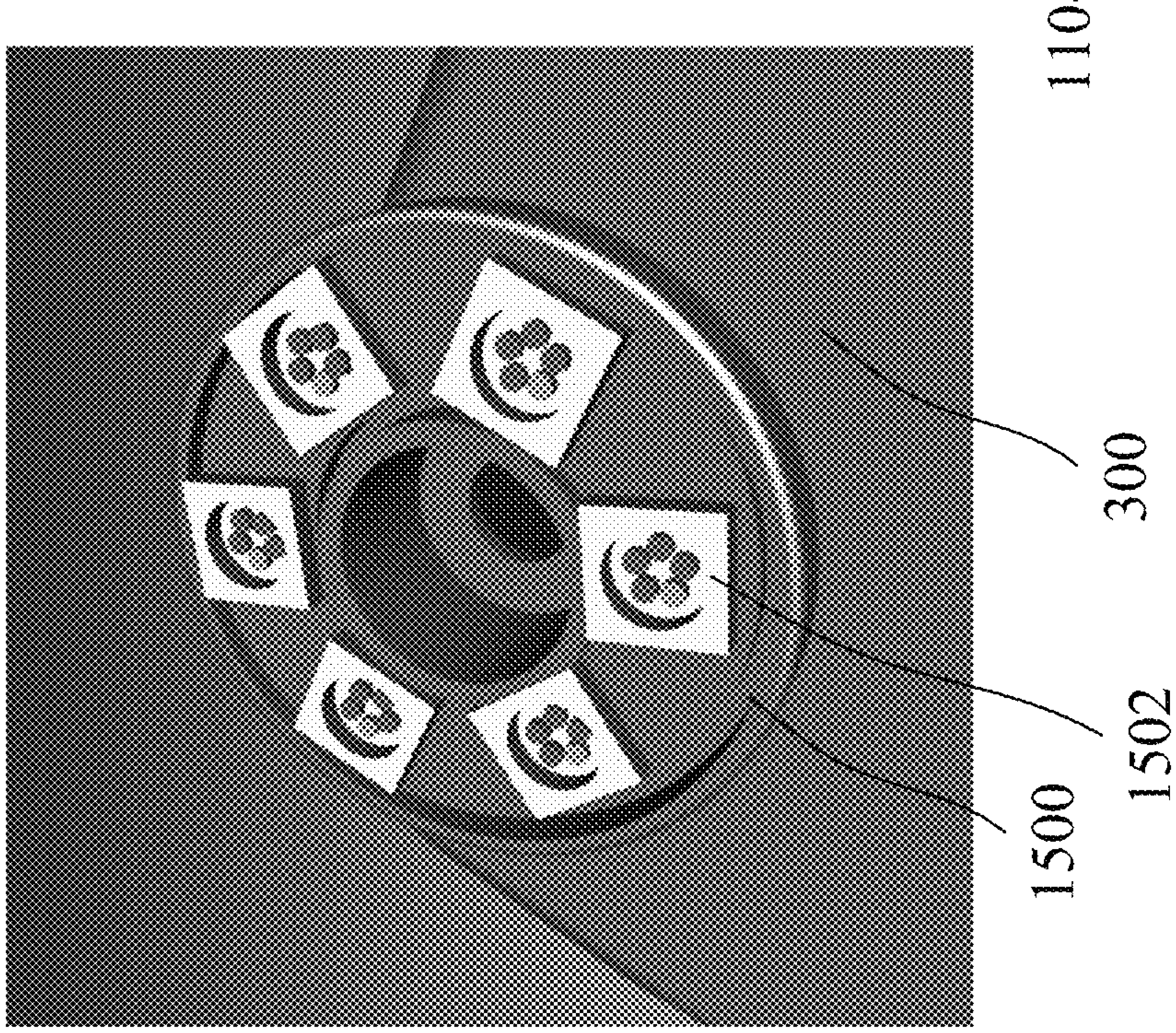


FIG. 15E

1600

A method comprising:

at an imaging device comprising a detector, a controller, and J light source sets for emitting light of K spectral ranges, wherein J is a positive integer of three or greater, K is a positive integer smaller than J, wherein each spectral range is different than any other spectral range in the K spectral ranges, wherein for each respective k^{th} spectral range in the K spectral ranges, the J light source sets comprise corresponding j_k light source set or sets, wherein j_k is a positive integer of one or greater, and , and wherein at least one program is non-transiently stored in the controller and executable by the controller, the at least one program causing the controller to perform the method of:

for each integer $k \in \{1, \ldots, K\}$:

1602

(A) concurrently firing lighting components of the j_k light source set or sets in the J light source sets for a k^{th} predetermined time period

1604

(B) collecting, using the detector, light during all or a portion of the k^{th} predetermined time period

thereby forming at least one digital image

two or more light source sets in the J light source sets emit light that is substantially limited to a first spectral range, and

one or more light source sets in the J light source sets emit light that is substantially limited to a second spectral range other than the first spectral range

one or more light source sets in the J light source sets emit light that is substantially limited to a third spectral range other than the first and second spectral ranges

FIG. 16

1700

A method comprising:

at an imaging device comprising one or more light source sets, a detector and a controller, wherein at least one program is non-transiently stored in the controller and executable by the controller, the at least one program causing the controller to perform the method of:

1702

(A) acquiring a reference image of a region of interest (ROI) by using the detector to collect light over a reference time period while the ROI is not exposed to any light emitted from the one or more light source sets, wherein the reference image comprises an array of pixels each corresponding to a sub-region in an array of sub-regions of the ROI

1704

(B) firing a first light source set while not firing any other light source set in the one or more light source sets, wherein the first light source set in the one or more light source sets emits light that is substantially limited to a first spectral range

the first time period is substantially the same as the reference time period

the first time period is between 1 millisecond and 100 milliseconds

the light emitted from each light source set in the one or more light source sets has an intensity higher than the light from an ambient

the imaging device further comprises an objective lens in optical communication with the detector, wherein the first light source set in the one or more light source sets comprises a plurality of lighting components that is radially distributed about the objective lens

17B

FIG. 17A

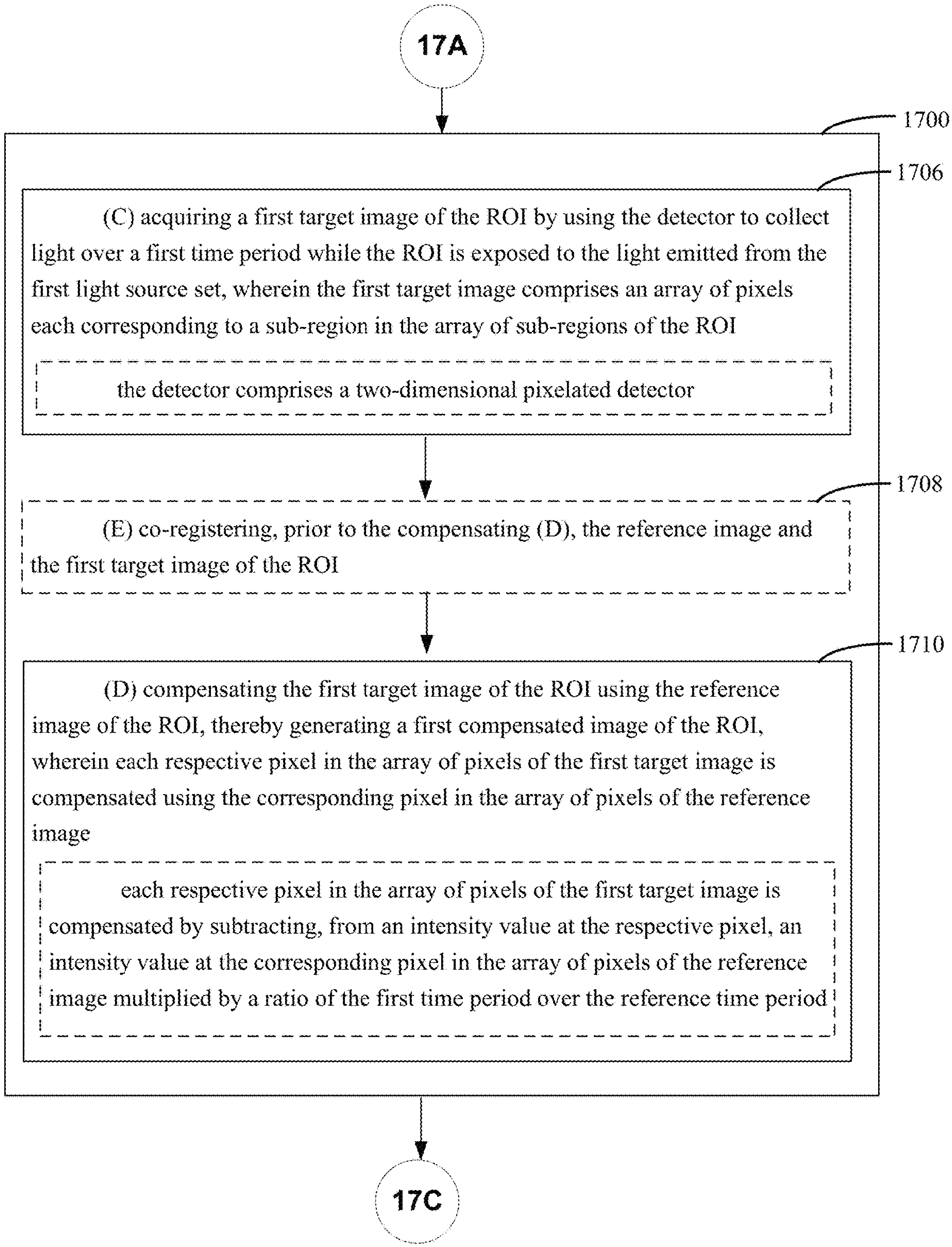

17A
1700
1706
(C) acquiring a first target image of the ROI by using the detector to collect light over a first time period while the ROI is exposed to the light emitted from the first light source set, wherein the first target image comprises an array of pixels each corresponding to a sub-region in the array of sub-regions of the ROI
the detector comprises a two-dimensional pixelated detector
1708
(E) co-registering, prior to the compensating (D), the reference image and the first target image of the ROI
1710
(D) compensating the first target image of the ROI using the reference image of the ROI, thereby generating a first compensated image of the ROI, wherein each respective pixel in the array of pixels of the first target image is compensated using the corresponding pixel in the array of pixels of the reference image
each respective pixel in the array of pixels of the first target image is compensated by subtracting, from an intensity value at the respective pixel, an intensity value at the corresponding pixel in the array of pixels of the reference image multiplied by a ratio of the first time period over the reference time period
17C

FIG. 17B

17B

1700

1712

(F) firing a second light source set while not firing any other light source set in the one or more light source sets, wherein the second light source set in the one or more light source sets emits light that is substantially limited to a second spectral range, and the second spectral range that is different than the first spectral range

1714

(G) acquiring a second target image of the ROI by using the detector to collect light over a second time period while the ROI is exposed to the light emitted from the second light source set, wherein the second target image comprises an array of pixels each corresponding to a sub-region in the array of sub-regions of the ROI

1716

(H) compensating the second target image of the ROI using the reference image of the ROI, thereby generating a second compensated image of the ROI, wherein each respective pixel in the array of pixels of the second target image is compensated using the corresponding pixel in the array of pixels of the reference image

each respective pixel in the array of pixels of the second target image is compensated by subtracting, from an intensity value at the respective pixel, an intensity value at the corresponding pixel in the array of pixels of the reference image multiplied by a ratio of the second time period over the reference time period

the second time period is substantially the same as the first time period and/or the reference time period

FIG. 17C

1800

A method comprising:

at an image device comprising a detector, a controller, and J light source sets for emitting light of K spectral ranges, wherein each spectral range is different than any other spectral range in the K spectral ranges, wherein for each respective k^{th} spectral range in the K spectral ranges, the J light source sets comprise corresponding j_k light source set or sets, wherein j_k is a positive integer of one or greater, and wherein at least one program is non-transiently stored in the controller and executable by the controller, the at least one program causing the controller to perform the method of:

J is a positive integer of three or greater and K is a positive integer smaller than J

1802

(A) acquiring a reference image of a region of interest (ROI) by using the detector to collect light over a reference time period while the ROI is not exposed to any light emitted from the one or more light source sets, wherein the reference image comprises an array of pixels each corresponding to a sub-region in an array of sub-regions of the ROI

for each integer $k \in \{1, \ldots, K\}$:

1804

(B) concurrently firing lighting components of the j_k light source set or sets in the J light source sets while not firing any other light source set in the J light source sets

1806

(C) acquiring a respectively target image of the ROI by using the detector to collect light over a respective k^{th} target time period while the ROI is exposed to the light emitted from the j_k light source set or sets, wherein the respective target image comprises an array of pixels each corresponding to a sub-region in the array of sub-regions of the ROI

1808

(E) co-registering, prior to the compensating (D), the reference image and the respective target image of the ROI

18B

FIG. 18A

18A

1800

for each integer $k \in \{1, \ldots, K\}$:

1810

(D) compensating the respective target image of the ROI using the reference image of the ROI, thereby generating a respective compensated image of the ROI, wherein each respective pixel in the array of pixels of the respective target image is compensated using the corresponding pixel in the array of pixels of the reference image

each respective pixel in the array of pixels of the respective target image is compensated by subtracting, from an intensity value at the respective pixel, an intensity value at the corresponding pixel in the array of pixels of the reference image multiplied by a ratio of the respective k^{th} target time period over the reference time period

1812

(F) combining each respective compensated image of the ROI generated using each respective light source set in the plurality of light source sets into a single hyperspectral / multispectral image

two or more light source sets in the J light source sets emit light that is substantially limited to a first spectral range, and

one or more light source sets in the J light source sets emit light that is substantially limited to a second spectral range other than the first spectral range

one or more light source sets in the J light source sets emit light that is substantially limited to a third spectral range other than the first and second spectral ranges

FIG. 18B

1900

A method comprising:

at an imaging device comprising an objective lens, a light source adjacent to the objective lens, a detector in optical communication with the objective lens, and a controller, wherein at least one program is non-transiently stored in the controller and executable by the controller, the at least one program causing the controller to perform the method of:

1902

(A) acquiring a target image of a region of interest (ROI) by using the detector to collect light over a target time period while the ROI is exposed to light emitted from the light source set, wherein the target image comprises an array of pixels each corresponding to a sub-region in an array of sub-regions of the ROI

the light source comprises one or more light source sets, each light source set comprising a plurality of lighting components that is radially distributed about the objective lens

the light source comprises J light source sets for emitting light of K spectral ranges, wherein each spectral range is different than any other spectral range in the K spectral ranges; for each respective k^{th} spectral range in the K spectral ranges, the J light source sets comprise corresponding j_k light source set or sets, wherein j_k is a positive integer of one or greater; and each light source set in the J light source sets comprises a plurality of lighting components that is radially distributed about the objective lens.

J is a positive integer of three or greater and K is a positive integer smaller than J

the ROI is a face of a subject

1904

(E) compensating, prior to the creating (B), the target image of the ROI using a reference image of the ROI, thereby generating a compensated image of the ROI, wherein the reference image of the ROI is acquired by using the detector to collect light over a reference time period while the ROI is not exposed to any light emitted from the light source, wherein each respective pixel in an array of pixels of the target image is compensated using the corresponding pixel in an array of pixels of the reference image, and wherein the creating (B) is performed on the compensated target image

19B

FIG. 19A

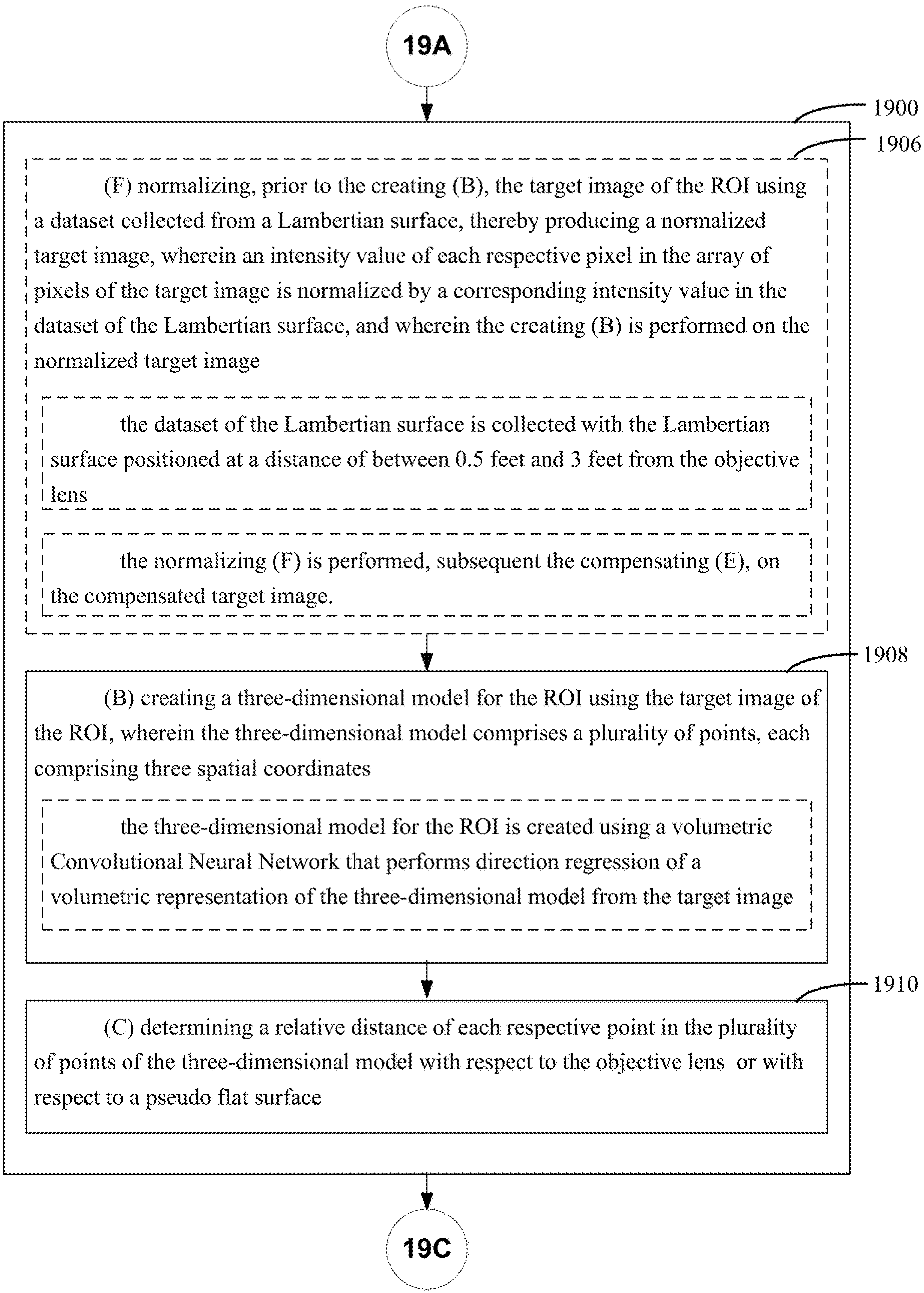

19A
1900
1906
(F) normalizing, prior to the creating (B), the target image of the ROI using a dataset collected from a Lambertian surface, thereby producing a normalized target image, wherein an intensity value of each respective pixel in the array of pixels of the target image is normalized by a corresponding intensity value in the dataset of the Lambertian surface, and wherein the creating (B) is performed on the normalized target image
the dataset of the Lambertian surface is collected with the Lambertian surface positioned at a distance of between 0.5 feet and 3 feet from the objective lens
the normalizing (F) is performed, subsequent the compensating (E), on the compensated target image.
1908
(B) creating a three-dimensional model for the ROI using the target image of the ROI, wherein the three-dimensional model comprises a plurality of points, each comprising three spatial coordinates
the three-dimensional model for the ROI is created using a volumetric Convolutional Neural Network that performs direction regression of a volumetric representation of the three-dimensional model from the target image
1910
(C) determining a relative distance of each respective point in the plurality of points of the three-dimensional model with respect to the objective lens or with respect to a pseudo flat surface
19C

FIG. 19B

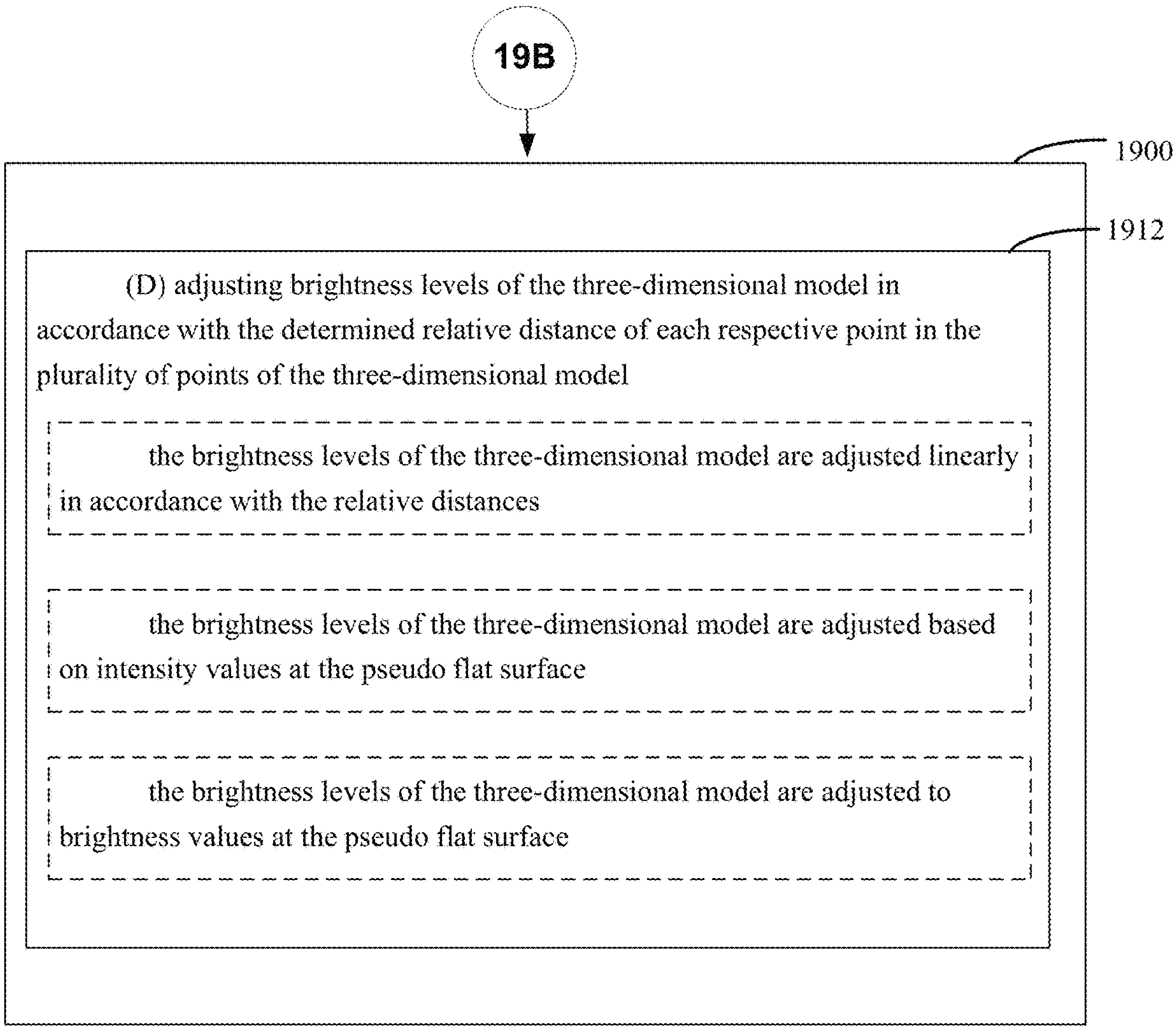

19B
1900
1912
(D) adjusting brightness levels of the three-dimensional model in accordance with the determined relative distance of each respective point in the plurality of points of the three-dimensional model
the brightness levels of the three-dimensional model are adjusted linearly in accordance with the relative distances
the brightness levels of the three-dimensional model are adjusted based on intensity values at the pseudo flat surface
the brightness levels of the three-dimensional model are adjusted to brightness values at the pseudo flat surface

FIG. 19C

SYSTEMS AND METHODS FOR SPECTRAL IMAGING WITH COMPENSATION FUNCTIONS

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is a continuation-in-part application of U.S. patent application Ser. No. 15/867,653 filed Jan. 10, 2018, now issued as U.S. Pat. No. 10,554,909, which claims priority to U.S. Provisional Patent Application No. 62/444,731, filed Jan. 10, 2017, entitled "Hyperspectral Transmitter," which are hereby incorporated by reference in their entirety.

BACKGROUND

Field

The present disclosure relates to an imaging device. More particularly, the present disclosure relates to systems and method for imaging using a plurality of light sources.

Description of Related Art

In general, hyperspectral imaging is an imaging technique that integrates multiple images of a subject or region of interest resolved at various spectral bands into a single image, known as a hyperspectral/multispectral image. Each image of the multiple images represents a narrow spectral band acquired over a continuous spectral range. For example, a hyperspectral/multispectral imaging system may acquire at least two images, with each image taken using a different spectral band. The multiple images of the subject or region or interest can for example be sequentially captured and processed to generate the desired hyperspectral image. For the multiple images to be useful in generating a high quality hyperspectral image, however, the multiple images must be similar in composition and orientation. For instance, the subject or region of interest of the multiple images must be positioned nearly identical in each frame to allow for seamless combination.

Hyperspectral imaging devices have been utilized in various industries, from geological and agricultural surveying to medical diagnosis. Within the medical field, hyperspectral imaging has been utilized to facilitate complex diagnosis and predict or analyze treatment outcomes. Other such uses of a hyperspectral imaging device include material composition analysis, biometrics and the like.

Despite the enormous potential for hyperspectral imaging and devices thereof, there exists numerous hurdles that prevent such devices from being universally implemented. Conventional hyperspectral imaging devices utilize high-end optics and expensive hardware, yielding an exceptionally high manufacturing cost. These devices are often large and bulky, requiring significant weight and/or size.

Prior hyperspectral imaging devices typically reduce the total energy of a given system by applying a plurality of filters to a given signal. Such systems require light having a high intensity to ensure suitable transmission quality through the filter, which often consumes a large amount of power.

Additionally, since the component images are captured sequentially, ensuring that all of the component images are properly aligned can be difficult. This is especially true in the medical and military industry where a clinician or responder is capturing images of a subject or region of interest that may move, or who may be positioned in a way that makes capturing images of the subject or region of interest difficult.

Thus, prior to the present disclosure there existed a need for a hyperspectral imaging device that greatly reduces time required to capture hyperspectral images at significantly reduced costs.

The information disclosed in this Background of the Invention section is only for enhancement of understanding of the general background of the invention and should not be taken as an acknowledgement or any form of suggestion that this information forms the prior art already known to a person skilled in the art.

BRIEF SUMMARY

Advantageously, the hyperspectral/multispectral imaging device detailed in the present disclosure address the shortcomings in the prior art detailed above.

Various aspects of the present disclosure are directed to providing a hyperspectral/multispectral imaging device, non-transitory computer comprising at least one executable program, and a method thereof.

Device Embodiments

One aspect of the present disclosure provides an imaging device comprising a housing having an exterior and an interior. The imaging device also includes an objective lens within the housing which is flush with a surface of the housing. Thus, the objective lens does not substantially extend past the surface of the housing. A plurality of light source sets is attached or integrated into the housing. Each respective light source set in the plurality of light sources sets comprises a plurality of lights that is uniformly radially distributed about the objective lens. A first light source set in the plurality of light source sets emits light that is substantially limited to a first spectral range, and a second light source set in the plurality of light source sets emits light that is substantially limited to a second spectral range other than the first spectral range. A single two-dimensional pixelated detector is disposed within the housing and in optical communication with the objective lens. The imaging device includes a controller, comprising at least one program non-transiently stored in the controller and executable by the controller. The at least one program causes the controller to perform a method of i) concurrently firing the plurality of lights in the first light source set for a first time period while not firing any other light source set in the plurality of light source sets, ii) collecting light from the objective lens during all or a portion of the first time period using the two-dimensional pixelated detector, iii) concurrently firing the plurality of lights in the second light source set for a second time period while not firing any other light source set in the plurality of light source sets, and iv) collecting light from the objective lens during all or a portion of the second time period using the two-dimensional pixelated detector, thereby forming at least one digital image.

In some embodiments, a single digital image is formed from a combination of the collecting ii) and the collecting iv).

In some embodiments, a first digital image is formed from the collecting ii) and a second digital image is formed from the collecting vi).

In some embodiments, the uniform radial distribution forms at least one concentric circle about the objective lens.

In some embodiments, each light source set in the plurality of light source sets consist of n light sources, where n is a positive integer greater than or equal to two. Each light source of a respective light source set is arranged with θ degrees of separation to another light source of the respective light source set, where

$$\theta_1 = \frac{360}{n}.$$

In some embodiments, a respective light source of each respective light source set is disposed at a same location.

In various embodiments, each light source of the respective light source set in the plurality of light source sets is arranged with θ_2 degrees of separation from an adjacent light source of a different light source set in the plurality of light source sets, wherein

$$\theta_2 = \frac{360}{kn}$$

and k is a number of light source sets.

In some embodiments, a wavelength spectra of emitted light from the plurality of light source sets is substantially limited by a plurality of optical filters. Each light source in the first light source set is filtered by a different bandpass filter in a first plurality of bandpass filters such that each bandpass filter in the first plurality of bandpass filters limits light emission to the first spectral range. Each light source in the second light source set is filtered by a different bandpass filter in a second plurality of bandpass filters such that each bandpass filter in the second plurality of bandpass filters limits light emission to the second spectral range.

In some embodiments, the plurality of optical filters comprises at least one longpass filter. In some embodiments, the plurality of optical filters comprises at least one shortpass filter.

In some embodiments, the first spectral range is 405±10 nanometers (nm) to 890±10 nm and the second wavelength band is 405±10 nm to 890±10 nm.

In some embodiments, the plurality of light source sets emit light at an intensity of 500 micro-candela (mcd) to 1500 mcd.

In some embodiments, the first time period is between 2 ms and 100 ms, and the second time period is between 2 milliseconds (ms) and 100 ms.

In some embodiments, a third light source set in the plurality of light source sets emits light that is substantially limited to a third spectral range or wavelength.

In some embodiments, k light source sets in the plurality of light source sets emit light that is substantially limited to k spectral ranges or wavelength(s).

In some embodiments, the objective lens is selected from the group consisting of a three dimensional (3D) binocular, a fiber optic, a fisheye lens, a macro lens, a microscopic lens, a normal lens, and a telephoto lens.

In some embodiments, the two-dimensional pixelated detector is selected from the group consisting of a charge-coupled device (CCD), a complementary metal-oxide-semiconductor (CMOS), a photo-cell, and a focal plane array.

In specific embodiments, the housing snap-fits to a mobile device.

In some embodiments, the imaging device is flush with a surface of the mobile device.

In various embodiments, the mobile device is selected from the group consisting of a smart phone, a personal digital assistant (PDA), an enterprise digital assistant, a tablet computer, and a digital camera.

Yet another aspect of the present disclosure provides a lighting device of an imaging device. The lighting device comprises a plurality of light source sets. Each respective light source set in the plurality of light source sets comprises a plurality of lighting components that is uniformly radially distributed about an objective lens of the imaging device. The plurality of light source sets comprises (i) two or more light source sets, each emitting light that is substantially limited to a first spectral range; and (ii) one or more light source sets, each emitting light that is substantially limited to a second spectral range other than the first spectral range.

In some embodiments, a collective lighting intensity produced by the two or more light source sets that emit light substantially limited to the first spectral range and a collective lighting intensity produced by the one or more light source sets that emit light substantially limited to the second spectral range are substantially the same.

In some embodiments, a collective lighting intensity produced by the two or more light source sets that emit light substantially limited to the first spectral range is between 500 micro-candela to 1500 micro-candela.

In some embodiments, the first spectral range is 305 nanometers (nm)±10 nm to 890 nm±10 nm and the second wavelength band is 305 nm±10 nm to 890 nm±10 nm.

In some embodiments, the first spectral range is selected in accordance with an absorption spectra of a first chromophore and the second spectral range is selected in accordance with an absorption spectra of a second chromophore.

In some embodiments, one of the first and second chromophores is melanin and the other of the first and second chromophores is hemoglobin.

In some embodiments, the lighting device further comprises: (iii) one or more light source sets, each emitting light that is substantially limited to a third spectral range other than the first and second spectral ranges.

In some embodiments, each light source set in the plurality of light source sets consists of n lighting components, wherein n is a positive integer of value two or greater, and each lighting component of a respective light source set is arranged with θ_1 degrees of separation to another lighting component of the respective light source set, wherein

$$\theta_1 = \frac{360}{n}.$$

Still another aspect of the present disclosure provides an imaging device comprising: (A) a housing, (B) an objective lens, C) J light source sets, (D) a detector, and E) a controller. The housing has an exterior and an interior. The objective lens is disposed within the housing and flush with a surface of the housing so that the objective lens does not substantially extend past the surface of the housing. The J light source sets are attached or integrated into the housing. J is a positive integer of three or greater, and K is a positive integer smaller than J. Each spectral range is different than any other spectral range in the K spectral ranges. For each respective k^{th} spectral range in the K spectral ranges, the J light source sets comprise corresponding j_k light source set or sets, wherein j_k is a positive integer of one or greater, and $\Sigma_{k=1}^{K} j_k = J$. Each respective light source set in the J light source sets comprises a plurality of lighting components that is uniformly radially distributed about the objective lens. The detector is disposed within the housing and in optical communication with the objective lens. At least one program is non-transiently stored in the controller and executable by the controller. When executed, the at least one program causes the controller to control operation of the plurality of light source sets and the detector.

In some embodiments, the detector is a single two-dimensional pixelated detector.

In some embodiments, the at least one program causing the controller to perform a method of: for each integer $k \in \{1, \ldots, K\}$, (A) concurrently firing lighting components of the j_k light source set or sets in the J light source sets for a k^{th} predetermined time period; and (B) collecting, using the detector, light during all or a portion of the k^{th} predetermined time period, thereby forming at least one digital image.

In some embodiments, two or more light source sets in the J light source sets emit light that is substantially limited to a first spectral range, and one or more light source sets in the J light source sets emit light that is substantially limited to a second spectral range other than the first spectral range.

In some embodiments, a collective lighting intensity produced by the two or more light source sets that emit light substantially limited to the first spectral range and a collective lighting intensity produced by the one or more light source sets that emit light substantially limited to the second spectral range are substantially the same.

In some embodiments, a collective lighting intensity produced by the two or more light source sets that emit light substantially limited to the first spectral range is between 500 micro-candela to 1500 micro-candela.

In some embodiments, the first spectral range is 305 nanometers (nm)±10 nm to 890 nm±10 nm and the second wavelength band is 305 nm±10 nm to 890 nm±10 nm.

In some embodiments, the first spectral range is selected in accordance with an absorption spectra of a first chromophore and the second spectral range is selected in accordance with an absorption spectra of a second chromophore.

In some embodiments, one of the first and second chromophores is melanin and the other of the first and second chromophores is hemoglobin.

In some embodiments, each light source set in the J light source sets consists of n lighting components, wherein n is a positive integer of value two or greater, and each lighting component of a respective light source set is arranged with θ_1 degrees of separation to another lighting component of the respective light source set, wherein

$$\theta_1 = \frac{360}{n}.$$

In some embodiments, one or more light source sets in the J light source sets emit light that is substantially limited to a third spectral range other than the first and second spectral ranges.

In some embodiments, a collective lighting intensity produced by the two or more light source sets that emit light substantially limited to the first spectral range, a collective lighting intensity produced by the one or more light source sets that emit light substantially limited to the second spectral range, and a collective lighting intensity produced by the one or more light source sets that emit light substantially limited to the third spectral range are substantially the same.

In some embodiments, the at least one program causing the controller to perform a method of: (i) concurrently firing the two or more light source sets that emit light substantially limited to the first spectral range while not firing any other light source set in the J light source sets; (ii) collecting light from the objective lens over a first time period using the detector; (iii) concurrently firing the one or more light source sets that emit light substantially limited to the second spectral range while not firing any other light source set in the J light source sets; and (iv) collecting light from the objective lens over a second time period using the detector, thereby forming at least one digital image.

Yet another aspect of the present disclosure provides a lighting device of an imaging device. The lighting device comprises J light source sets for emitting light of N spectral ranges. J is a positive integer of three or greater and K is a positive integer smaller than J. Each spectral range is different than any other spectral range in the K spectral ranges. For each respective k^{th} spectral range in the K spectral ranges, the J light source sets comprise corresponding j_k light source set or sets, wherein j_k is a positive integer of one or greater, and $\Sigma_{k=1}^{K} j_k = J$. Each respective light source set in the J light source sets comprises a plurality of lighting components configured to be uniformly radially distributed about an objective lens of the imaging device.

In some embodiments, two or more light source sets in the J light source sets emit light that is substantially limited to a first spectral range; and one or more light source sets in the J light source sets emit light that is substantially limited to a second spectral range other than the first spectral range.

In some embodiments, a collective lighting intensity produced by the two or more light source sets that emit light substantially limited to the first spectral range and a collective lighting intensity produced by the one or more light source sets that emit light substantially limited to the second spectral range are substantially the same.

In some embodiments, a collective lighting intensity produced by the two or more light source sets that emit light substantially limited to the first spectral range is between 500 micro-candela to 1500 micro-candela.

In some embodiments, the first spectral range is 305 nanometers (nm)±10 nm to 890 nm±10 nm and the second wavelength band is 305 nm±10 nm to 890 nm±10 nm.

In some embodiments, the first spectral range is selected in accordance with an absorption spectra of a first chromophore and the second spectral range is selected in accordance with an absorption spectra of a second chromophore.

one of the first and second chromophores is melanin and the other of the first and second chromophores is hemoglobin.

In some embodiments, one or more light source sets in the J light source sets emit light that is substantially limited to a third spectral range other than the first and second spectral ranges.

In some embodiments, each light source set in the J light source sets consists of n lighting components, wherein n is a positive integer of value two or greater, and each lighting component of a respective light source set is arranged with θ_1 degrees of separation to another lighting component of the respective light source set, wherein

$$\theta_1 = \frac{360}{n}.$$

Non-Transitory Computer Readable Storage Medium Embodiments

Another aspect of the present disclosure provides a non-transitory computer readable storage medium comprising instructions for execution by one or more processors to perform a hyperspectral/multispectral imaging regimen using a mobile device comprising the one or more processors, an objective lens, a two-dimensional pixelated detector in optical communication with the objective lens, and i light source sets, the instructions comprising, for each integer i in the set {1, . . . , i, . . . , k}, wherein k is a positive integer of two or greater. The instructions include instructions for instructing an i^{th} plurality of lights uniformly radially distributed about the objective lens in the i^{th} light source set in the plurality of light source sets to fire for an i^{th} time period while not firing any other light source set in the plurality of light source sets. The instructions further include instructions for instructing the two-dimensional pixelated detector to collect light from the objective lens during all or a portion of the i^{th} time period, thereby forming at least one digital image.

In some embodiments, the non-transitory computer readable storage medium includes instructions for instructing a plurality of lights uniformly radially distributed about the objective lens in a k^{th} light source set in the plurality of light source sets to fire for a predetermined time period while not firing any other light source set in the plurality of light source sets. Further, the instructions include instructions for instructing the two-dimensional pixelated detector to collect a k^{th} image during the predetermined time period, and combining at least the first through k^{th} images to form a hyperspectral/multispectral image.

The present disclosure also provides one or more non-transitory computer readable storage mediums comprising instructions for imaging at an imaging device including but not limited to the imaging devices disclosed herein. The instructions are non-transiently stored in a controller, including but not limited to those disclosed herein, and executable by the controller. When executed, the instructions cause the controller to perform one or more methods, including but not limited to those disclosed herein such as methods for removing ambient light contribution and compensating incidence angle and/or distance effect.

Method Embodiments

Another aspect of the present disclosure provides a method for performing a hyperspectral/multispectral imaging regimen at a mobile device comprising one or more processors, memory storing one or more programs for execution by the one or more processors, an objective lens, a controller, a two-dimensional pixelated detector in optical communication with the objective lens, and a plurality of light source sets, attached to or integrated with the mobile device, comprising a first light source set in the plurality of light source sets and a second light source set in the plurality of light source sets. The one or more programs singularly or collectively instruct, through the controller, the first light source set in the plurality of light source sets to fire for a first time period. The one or more programs further instruct, through the controller, the two-dimensional pixelated detector to acquire a first image during the first time period. The one or more programs further instruct, through the controller, the second light source set in the plurality of light source sets to fire for a second time period. The one or more programs further instruct, through the controller, the two-dimensional pixelated detector to acquire a second image during the second time period. The one or more programs further combine at least the first image and the second image to form a hyperspectral/multispectral image.

In some embodiments, the second instance of instructing occurs concurrently with the first instance of instructing for a time period equal to the first time period plus the second time period, the third instance of instructing occurs subsequent completion of the first instructing, and the fourth instance of instructing is omitted.

In some embodiments, one or more programs instruct, through the controller, a k^{th} light source set in the plurality of light source sets to fire for a predetermined time period, and instruct, through the controller, the two-dimensional pixelated detector to collect a k^{th} image during the predetermined time period, and combining at least the first through k^{th} images to form a hyperspectral/multispectral image.

Another aspect of the present disclosure provides a method for hyperspectral/multispectral imaging. The method is performed at an imaging device comprising a detector, a controller, and J light source sets for emitting light of K spectral ranges. J is a positive integer of three or greater and K is a positive integer smaller than J. Each spectral range is different than any other spectral range in the K spectral ranges. For each respective k^{th} spectral range in the K spectral ranges, the J light source sets comprise corresponding j_k light source set or sets, wherein j_k is a positive integer of one or greater, and $\Sigma_{k=1}^{K} j_k = J$. At least one program is non-transiently stored in the controller and executable by the controller, the at least one program causing the controller to perform the method of: for each integer $k \in \{1, \ldots, K\}$, (A) concurrently firing lighting components of the j_k light source set or sets in the J light source sets for a k^{th} predetermined time period; and (B) collecting, using the detector, light during all or a portion of the k^{th} predetermined time period, thereby forming at least one digital image.

In some embodiments, two or more light source sets in the J light source sets emit light that is substantially limited to a first spectral range, and one or more light source sets in the J light source sets emit light that is substantially limited to a second spectral range other than the first spectral range.

In some embodiments, one or more light source sets in the J light source sets emit light that is substantially limited to a third spectral range other than the first and second spectral ranges.

Yet another aspect of the present disclosure provides a method for removing ambient light contribution. The method is performed at an imaging device comprising one or more light source sets, a detector and a controller. At least one program is non-transiently stored in the controller and executable by the controller. When executed, the at least one program causes the controller to perform the method comprising: (A) acquiring a reference image of a region of interest (ROI) by using the detector to collect light over a reference time period while the ROI is not exposed to any light emitted from the one or more light source sets, wherein the reference image comprises an array of pixels each corresponding to a sub-region in an array of sub-regions of the ROI; (B) firing a first light source set while not firing any other light source set in the one or more light source sets, wherein the first light source set in the one or more light source sets emits light that is substantially limited to a first spectral range; (C) acquiring a first target image of the ROI by using the detector to collect light over a first time period while the ROI is exposed to the light emitted from the first light source set, wherein the first target image comprises an array of pixels each corresponding to a sub-region in the array of sub-regions of the ROI; and (D) compensating the first target image of the ROI using the reference image of the

ROI, thereby generating a first compensated image of the ROI, wherein each respective pixel in the array of pixels of the first target image is compensated using the corresponding pixel in the array of pixels of the reference image.

In some embodiments, each respective pixel in the array of pixels of the first target image is compensated by subtracting, from an intensity value at the respective pixel, an intensity value at the corresponding pixel in the array of pixels of the reference image multiplied by a ratio of the first time period over the reference time period.

In some embodiments, the first time period is substantially the same as the reference time period.

In some embodiments, the first time period is between 1 millisecond and 100 milliseconds.

In some embodiments, the detector comprises a two-dimensional pixelated detector.

In some embodiments, the imaging device further comprises an objective lens in optical communication with the detector, wherein the first light source set in the one or more light source sets comprises a plurality of lighting components that is radially distributed about the objective lens.

In some embodiments, the light emitted from each light source set in the one or more light source sets has an intensity higher than the light from an ambient.

In some embodiments, the method further comprises: (E) co-registering, prior to the compensating (D), the reference image and the first target image of the ROI.

In some embodiments, the method further comprises: (F) firing a second light source set while not firing any other light source set in the one or more light source sets, wherein the second light source set in the one or more light source sets emits light that is substantially limited to a second spectral range, and the second spectral range that is different than the first spectral range; (G) acquiring a second target image of the ROI by using the detector to collect light over a second time period while the ROI is exposed to the light emitted from the second light source set, wherein the second target image comprises an array of pixels each corresponding to a sub-region in the array of sub-regions of the ROI; and (H) compensating the second target image of the ROI using the reference image of the ROI, thereby generating a second compensated image of the ROI, wherein each respective pixel in the array of pixels of the second target image is compensated using the corresponding pixel in the array of pixels of the reference image.

In some embodiments, each respective pixel in the array of pixels of the second target image is compensated by subtracting, from an intensity value at the respective pixel, an intensity value at the corresponding pixel in the array of pixels of the reference image multiplied by a ratio of the second time period over the reference time period.

In some embodiments, the second time period is substantially the same as the first time period or as the reference time period.

Further another aspect of the present disclosure provides another method for removing ambient light contribution. The method is performed at an image device comprising a detector, a controller, and J light source sets for emitting light of K spectral ranges, wherein each spectral range is different than any other spectral range in the K spectral ranges, wherein for each respective k^{th} spectral range in the K spectral ranges, the J light source sets comprise corresponding j_k light source set or sets, wherein j_k is a positive integer of one or greater, and $\Sigma_{k=1}^{K} j_k = J$. At least one program is non-transiently stored in the controller and executable by the controller. When executed, the at least one program causing the controller to perform the method comprising: (A) acquiring a reference image of a region of interest (ROI) by using the detector to collect light over a reference time period while the ROI is not exposed to any light emitted from the one or more light source sets, wherein the reference image comprises an array of pixels each corresponding to a sub-region in an array of sub-regions of the ROI. For each integer $k \in \{1, \ldots, K\}$, the method further comprises: concurrently firing lighting components of the j_k light source set or sets in the J light source sets while not firing any other light source set in the J light source sets; (C) acquiring a respectively target image of the ROI by using the detector to collect light over a respective k^{th} target time period while the ROI is exposed to the light emitted from the j_k light source set or sets, wherein the respective target image comprises an array of pixels each corresponding to a sub-region in the array of sub-regions of the ROI; and (D) compensating the respective target image of the ROI using the reference image of the ROI, thereby generating a respective compensated image of the ROI, wherein each respective pixel in the array of pixels of the respective target image is compensated using the corresponding pixel in the array of pixels of the reference image.

In some embodiments, each respective pixel in the array of pixels of the respective target image is compensated by subtracting, from an intensity value at the respective pixel, an intensity value at the corresponding pixel in the array of pixels of the reference image multiplied by a ratio of the respective k^{th} target time period over the reference time period.

In some embodiments, the method further comprises: (E) co-registering, prior to the compensating (D), the reference image and the respective target image of the ROI.

In some embodiments, the method further comprises: (F) combining each respective compensated image of the ROI generated using each respective light source set in the plurality of light source sets into a single hyperspectral/multispectral image.

In some embodiments, J is a positive integer of three or greater and K is a positive integer smaller than J.

In some embodiments, two or more light source sets in the J light source sets emit light that is substantially limited to a first spectral range, and one or more light source sets in the J light source sets emit light that is substantially limited to a second spectral range other than the first spectral range.

In some embodiments, one or more light source sets in the J light source sets emit light that is substantially limited to a third spectral range other than the first and second spectral ranges.

Still another of the present disclosure provides a method for compensating incidence angle and/or distance effects. The method is performed at an imaging device comprising an objective lens, a light source adjacent to the objective lens, a detector in optical communication with the objective lens, and a controller. At least one program is non-transiently stored in the controller and executable by the controller. When executed, the at least one program causes the controller to perform the method comprising: (A) acquiring a target image of a region of interest (ROI) by using the detector to collect light over a target time period while the ROI is exposed to light emitted from the light source set, wherein the target image comprises an array of pixels each corresponding to a sub-region in an array of sub-regions of the ROI; (B) creating a three-dimensional model for the ROI using the target image of the ROI, wherein the three-dimensional model comprises a plurality of points, each comprising three spatial coordinates; (C) determining a relative distance of each respective point in the plurality of points of the three-dimensional model with respect to the objective lens or with respect to a pseudo flat surface; and (D) adjusting brightness levels of the three-dimensional model in accordance with the determined relative distance of each respective point in the plurality of points of the three-dimensional model.

In some embodiments, the method further comprises: (E) compensating, prior to the creating (B), the target image of the ROI using a reference image of the ROI, thereby generating a compensated image of the ROI, wherein the reference image of the ROI is acquired by using the detector to collect light over a reference time period while the ROI is not exposed to any light emitted from the light source, wherein each respective pixel in an array of pixels of the target image is compensated using the corresponding pixel in an array of pixels of the reference image, and wherein the creating (B) is performed on the compensated target image. In an amendment, the method further comprises: (G) normalizing, subsequent the compensating (E) and prior to the creating (B), the compensated target image of the ROI using a dataset collected from a Lambertian surface, thereby producing a normalized target image, wherein an intensity value of each respective pixel in the array of pixels of the compensated target image is normalized by a corresponding intensity value in the dataset of the Lambertian surface, and wherein the creating (B) is performed on the normalized target image.

In some embodiments, the method further comprises: (F) normalizing, prior to the creating (B), the target image of the ROI using a dataset collected from a Lambertian surface, thereby producing a normalized target image, wherein an intensity value of each respective pixel in the array of pixels of the target image is normalized by a corresponding intensity value in the dataset of the Lambertian surface, and wherein the creating (B) is performed on the normalized target image.

In some embodiments, the dataset of the Lambertian surface is collected with the Lambertian surface positioned at a distance of between 0.5 feet and 3 feet from the objective lens.

In some embodiments, the light source comprises one or more light source sets, each light source set comprising a plurality of lighting components that is radially distributed about the objective lens.

In some embodiments, the light source comprises J light source sets for emitting light of K spectral ranges, wherein each spectral range is different than any other spectral range in the K spectral ranges; for each respective k^{th} spectral range in the K spectral ranges, the J light source sets comprise corresponding j_k light source set or sets, wherein j_k is a positive integer of one or greater, and $\Sigma_{k=1}^{K} j_k = J$; and each light source set in the J light source sets comprises a plurality of lighting components that is radially distributed about the objective lens.

In some embodiments, J is a positive integer of three or greater and K is a positive integer smaller than J.

In some embodiments, the three-dimensional model for the ROI is created using a volumetric Convolutional Neural Network that performs direction regression of a volumetric representation of the three-dimensional model from the target image.

In some embodiments, the brightness levels of the three-dimensional model are adjusted linearly in accordance with the relative distances.

In some embodiments, the brightness levels of the three-dimensional model are adjusted based on intensity values at the pseudo flat surface.

In some embodiments, the brightness levels of the three-dimensional model are adjusted to brightness values at the pseudo flat surface.

In some embodiments, the ROI is a face of a subject.

The lighting device, imaging device, method and non-transitory computer readable storage medium of the present invention have other features and advantages that will be apparent from, or are set forth in more detail in, the accompanying drawings, which are incorporated herein, and the following Detailed Description, which together serve to explain certain principles of exemplary embodiments of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an isometric view of an imaging device according to an exemplary embodiment of the present disclosure;

FIG. **2** illustrates a mobile device associated with an imaging device according to an exemplary embodiment of the present disclosure;

FIG. **3** a front schematic view of an imaging device according to an exemplary embodiment of the present disclosure;

FIG. **4** is a front schematic view of an imaging device according to another exemplary embodiment of the present disclosure;

FIG. **5** is a front schematic view of an imaging device according to yet another exemplary embodiment of the present disclosure;

FIG. **6** is a side schematic view of an imaging device and a mobile device according to a further exemplary embodiment of the present disclosure;

FIG. **7** is an enlarged schematic view of a plurality of light source sets according to an exemplary embodiment of the present disclosure;

FIG. **8** is an enlarged schematic view of a plurality of light source sets according to another exemplary embodiment of the present disclosure;

FIG. **9** is a rear schematic view of an imaging device according to an exemplary embodiment of the present disclosure;

FIG. **10** collectively illustrates a flow chart of methods for imaging discrete wavelength bands using a device in accordance with an embodiment of the present disclosure, in which optional steps or embodiments are indicated by dashed boxes;

FIG. **11**, FIG. **12**, and FIG. **13** are illustrations of a user interface for at least one executable program according to an exemplary embodiment of the present disclosure; and

FIG. **14**A, FIG. **14**B, FIG. **14**C, FIG. **14**D, and FIG. **14**E represent various images according to an exemplary embodiment of the present disclosure;

FIG. **15**A illustrates a lighting device according to an exemplary embodiment of the present disclosure;

FIG. **15**B illustrates a lighting device according to another exemplary embodiment of the present disclosure;

FIG. **15**C illustrates an imaging device according to an exemplary embodiment of the present disclosure;

FIG. **15**D is a partially enlarged view of FIG. **15**C;

FIG. **15**E illustrates an imaging device according to another exemplary embodiment of the present disclosure;

FIG. **15**F is a partially enlarged view of FIG. **15**E;

FIG. **16** illustrates a flow chart of methods for imaging in accordance with an embodiment of the present disclosure, in which optional steps or embodiments are indicated by dashed boxes;

FIG. **17**A, FIG. **17**B, and FIG. **17**C collectively illustrate a flow chart of methods for imaging in accordance with another embodiment of the present disclosure, in which optional steps or embodiments are indicated by dashed boxes;

FIG. **18**A and FIG. **18**B collectively illustrate a flow chart of methods for imaging in accordance with another embodiment of the present disclosure, in which optional steps or embodiments are indicated by dashed boxes; and

FIG. **19**A, FIG. **19**B, and FIG. **19**C collectively illustrate a flow chart of methods for imaging in accordance with another embodiment of the present disclosure, in which optional steps or embodiments are indicated by dashed boxes.

It should be understood that the appended drawings are not necessarily to scale, presenting a somewhat simplified representation of various features illustrative of the basic principles of the invention. The specific design features of the present invention as disclosed herein, including, for example, specific dimensions, orientations, locations, and shapes will be determined in part by the particular intended application and use environment.

In the figures, reference numbers refer to the same or equivalent parts of the present invention throughout the several figures of the drawing.

DETAILED DESCRIPTION

Reference will now be made in detail to various embodiments of the present invention(s), examples of which are illustrated in the accompanying drawings and described below. While the invention(s) will be described in conjunction with exemplary embodiments, it will be understood that the present description is not intended to limit the invention (s) to those exemplary embodiments. On the contrary, the invention(s) is/are intended to cover not only the exemplary embodiments, but also various alternatives, modifications, equivalents and other embodiments, which may be included within the spirit and scope of the invention as defined by the appended claims.

It will also be understood that, although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first subject could be termed a second subject, and, similarly, a second subject could be termed a first subject, without departing from the scope of the present disclosure. The first subject and the second subject are both subjects, but they are not the same subject. Furthermore, the terms "subject" and "user" are used interchangeably herein. Additionally, a first light source set could be termed a second light source set, and, similarly, a second light source set could be termed a first light source set, without departing from the scope of the present disclosure. The first light source set and the second light source set are both light source sets, but they are not the same light source set.

As used herein, the term "if" may be construed to mean "when" or "upon" or "in response to determining" or "in response to detecting," depending on the context. Similarly, the phrase "if it is determined" or "if [a stated condition or event] is detected" may be construed to mean "upon determining" or "in response to determining" or "upon detecting [the stated condition or event]" or "in response to detecting [the stated condition or event]," depending on the context.

Furthermore, when a reference number is given an "i^{th}" denotation, the reference number refers to a generic component, set, or embodiment. For instance, a light source set termed "light source set **110**-*i*" refers to the i^{th} in a plurality of light source sets.

Various aspects of the present disclosure are directed to providing a hyperspectral/multispectral imaging device, a non-transitory computer readable storage medium comprising instructions for one or more programs to operate the given device, and a method thereof.

An imaging device of the present disclosure can be utilized in a plurality of fields and industries. In one implementation, an imaging device can be utilized for medical and skin care purposes. These uses comprise cosmetic applications, skin health and management, sun damage monitoring, acne progression and treatment effectiveness mapping, wrinkle management, treatment and topical application analysis, general dermatology, vascular analysis, three dimensional imaging, and the like. Cases can vary from capturing regions of interest as small as tens or hundreds of microns such as pore, blood vessel, and wrinkle detection to regions of interest of approximately 500 cm^2 for uses such as facial three dimensional mapping and imaging.

In another implementation, an imaging device of the present disclosure can be utilized for agriculture science. Agriculture science comprises normalized difference vegetation index (NDVI) calculation and more advance vegetation indices. In some embodiments, the imaging device comprises visible and infrared light which can be polarized to reduce adverse lighting effects. Regions of interest in agriculture science and geology cases can range from 1 m^2 or less such as an individual tree to hundreds of square meters such as a farm. In such large region of interest cases, an array of imaging devices can be utilized.

In another implementation, an imaging device of the present disclosure can be utilized for military and security purposes. Military and security purposes comprise biometrics such as border checkpoint security, facial alteration counter-measures, material absorption on skin, clothes, surfaces, and the like.

In one implementation, as described herein, a hyperspectral/multispectral imaging device, and method, is described that concurrently captures multiple images, wherein each image is captured in a predetermined spectral range.

In another implementation, as described herein, a hyperspectral/multispectral imaging device, and method, is described that captures an image in a predetermined time period and concurrently fires a plurality of light source sets during the predetermined time period. The present method allows multiple discrete spectral ranges or wavelengths to be captured in a single image. Thus, a subject does not need to maintain perfect alignment between the imaging device and a subject to capture a high quality hyperspectral image.

FIG. **1** illustrates an exemplary embodiment of a hyperspectral/multispectral imaging device **100**, a housing **300** having an exterior and an interior, and a mobile device **400**. In the present embodiment, the housing **300** is attached to the mobile device **400**. In such embodiments, the housing **300** typically snap-fits to the mobile device **400**; however, the present disclosure is not limited thereto. In some embodiments, the housing **300** is integrated, or embedded, with the mobile device **400**.

FIG. **2** provides a description of a mobile device **400** that can be used with the present disclosure. The mobile device **400** has one or more processing units (CPU's) **402**, peripherals interface **470**, memory controller **468**, a network or other communications interface **420**, a memory **407** (e.g., random access memory), a user interface **406**, the user interface **406** including a display **408** and input **410** (e.g., keyboard, keypad, touch screen), an optional accelerometer **417**, an optional GPS **419**, optional audio circuitry **472**, an optional speaker **460**, an optional microphone **462**, one or more optional intensity sensors **464** for detecting intensity of contacts on the device **102** (e.g., a touch-sensitive surface such as a touch-sensitive display system **408** of the device **102**), optional input/output (I/O) subsystem **466**, one or more communication busses **412** for interconnecting the aforementioned components, and a power system **418** for powering the aforementioned components.

In some embodiments, the input **410** is a touch-sensitive display, such as a touch-sensitive surface. In some embodiments, the user interface **406** includes one or more soft keyboard embodiments. The soft keyboard embodiments may include standard (QWERTY) and/or non-standard configurations of symbols on the displayed icons. In some embodiments, the mobile device **400** further comprises a display, and the method further comprises displaying the first image on the display. In some embodiments, and the displayed image is enlargeable or reducible by human touch to the touch screen. In some embodiments, the display is configured for focusing an image of a surface of a subject acquired by the two-dimensional pixelated detector.

Device **402** optionally includes, in addition to accelerometer(s) **417**, a magnetometer and a GPS **419** (or GLONASS or other global navigation system) receiver for obtaining information concerning the location and orientation (e.g., portrait or landscape) of the mobile device **400**.

It should be appreciated that the mobile device **400** is only one example of a multifunction device that may be used by users when engaging with imaging device **100**, and that mobile device **400** optionally has more or fewer components than shown, optionally combines two or more components, or optionally has a different configuration or arrangement of the components. The various components shown in FIG. **2** are implemented in hardware, software, firmware, or a combination thereof, including one or more signal processing and/or application specific integrated circuits.

Memory **407** optionally includes high-speed random access memory and optionally also includes non-volatile memory, such as one or more magnetic disk storage devices, flash memory devices, or other non-volatile solid-state memory devices. Access to memory **407** by other components of mobile device **400**, such as CPU(s) **407** is, optionally, controlled by memory controller **468**.

Peripherals interface **470** can be used to couple input and output peripherals of the mobile device **400** to CPU(s) **402** and memory **407**. The one or more processors **402** run or execute various software programs and/or sets of instructions stored in memory **407** to perform various functions for mobile device **400** and to process data.

In some embodiments, peripherals interface **470**, CPU(s) **402**, and memory controller **468** are, optionally, implemented on a single chip. In some other embodiments, they are, optionally, implemented on separate chips.

The RF (radio frequency) circuitry **420** of network interface **420** receives and sends RF signals, also called electromagnetic signals. RF circuitry **420** converts electrical signals to/from electromagnetic signals and communicates with communications networks and other communications devices via the electromagnetic signals. RF circuitry **420** optionally includes well-known circuitry for performing these functions, including but not limited to an antenna system, an RF transceiver, one or more amplifiers, a tuner, one or more oscillators, a digital signal processor, a CODEC chipset, a subscriber identity module (SIM) card, memory, and so forth. RF circuitry **420** optionally communicates with networks **606**. In some embodiments, network circuitry does not include RF circuitry and, in fact, is connected to network **606** through one or more hard wires (e.g., an optical cable, a coaxial cable, or the like).

Examples of networks **606** include, but are not limited to, the World Wide Web (WWW), an intranet and/or a wireless network, such as a cellular telephone network, a wireless local area network (LAN) and/or a metropolitan area network (MAN), and other devices by wireless communication. The wireless communication optionally uses any of a plurality of communications standards, protocols and technologies, including but not limited to Global System for Mobile Communications (GSM), Enhanced Data GSM Environment (EDGE), high-speed downlink packet access (HSDPA), high-speed uplink packet access (HSDPA), Evolution, Data-Only (EV-DO), HSPA, HSPA+, Dual-Cell HSPA (DC-HSPDA), long term evolution (LTE), near field communication (NFC), wideband code division multiple access (W-CDMA), code division multiple access (CDMA), time division multiple access (TDMA), Bluetooth, Wireless Fidelity (Wi-Fi) (e.g., IEEE 802.11a, IEEE 802.11ac, IEEE 802.11ax, IEEE 802.11b, IEEE 802.11g and/or IEEE 802.11n), voice over Internet Protocol (VoIP), Wi-MAX, a protocol for e-mail (e.g., Internet message access protocol (IMAP) and/or post office protocol (POP)), instant messaging (e.g., extensible messaging and presence protocol (XMPP), Session Initiation Protocol for Instant Messaging and Presence Leveraging Extensions (SIMPLE), Instant Messaging and Presence Service (IMPS)), and/or Short Message Service (SMS), or any other suitable communication protocol, including communication protocols not yet developed as of the filing date of this document.

In some embodiments, audio circuitry **472**, speaker **460**, and microphone **462** provide an audio interface between a user and device **400**. The audio circuitry **472** receives audio data from peripherals interface **470**, converts the audio data to an electrical signal, and transmits the electrical signal to speaker **460**. Speaker **460** converts the electrical signal to human-audible sound waves. Audio circuitry **472** also receives electrical signals converted by microphone **462** from sound waves. Audio circuitry **472** converts the electrical signal to audio data and transmits the audio data to peripherals interface **470** for processing. Audio data is, optionally, retrieved from and/or transmitted to memory **407** and/or RF circuitry **420** by peripherals interface **470**.

In some embodiments, power system **418** optionally includes a power management system, one or more power sources (e.g., battery, alternating current (AC)), a recharging system, a power failure detection circuit, a power converter or inverter, a power status indicator (e.g., a light-emitting diode (LED)) and any other components associated with the generation, management and distribution of power in portable devices. In some embodiments, such as various embodiments where the housing **300** is integrated with the mobile device **400**, battery **240**, power management circuit **260**, and communication interface **280** can be components of the mobile device **400**, such as Power system **418** and network interface **420**.

In some embodiments, the mobile device **400** optionally also includes one or more two-dimensional pixelated detectors **473**. Two-dimensional pixelated detector **473** optionally includes a charge-coupled device (CCD), a complementary metal-oxide-semiconductor (CMOS) phototransistors, a photo-cell, and a focal plane array. Two-dimensional pixelated detector **473** receives light from the environment, and communicates with one or more lens, such as objective lens **210**, and converts the light to data representing an image. In conjunction with imaging module **431** (also called a camera module), two-dimensional pixelated detector **473** optionally captures still images and/or video. In some embodiments, a two-dimensional pixelated detector is located on the back of mobile device **400**, opposite display system **408** on the front of the device, so that the touch screen is enabled for use as a viewfinder for still and/or video image acquisition. In some embodiments, another two-dimensional pixelated detector is located on the front of the mobile device **400**. In the exemplary embodiment, the two-dimensional pixelated detector is disposed within the housing **300**.

As illustrated in FIG. **2**, a device **400** preferably comprises an operating system **422** that includes procedures for handling various basic system services. Operating system **422** (e.g., iOS, DARWIN, RTXC, LINUX, UNIX, OS X, WINDOWS, or an embedded operating system such as VxWorks) includes various software components and/or drivers for controlling and managing general system tasks (e.g., memory management, storage device control, power management, etc.) and facilitates communication between various hardware and software components.

In some embodiments, a device **400** further comprises an electronic address **620** (a mobile phone number, social media account, or e-mail address) associated with the corresponding user that is used in some embodiments by application **500** for communication.

In some embodiments, meta data is associated with captured multimedia, such as a device identifier (e.g., identifying the device of a group of devices that captured the multimedia item, which may include an arbitrary identifier, a MAC address, a device serial number, etc.), temporal meta data (e.g., date and time of a corresponding capture), location data (e.g., GPS coordinates of the location at which multimedia item was captured), a multimedia capture frequency (e.g., the frequency at which a stream of images is captured), device configuration settings (e.g., image resolution captured multimedia items, frequency ranges that the pixilated detector of a client device **104** is configured to detect), and/or other camera data or environmental factors associated with captured multimedia. Incorporated by reference in the present document are U.S. Pub. No. 2017/0323472 METHODS AND SYSTEMS FOR SURFACE INFORMATICS BASED DETECTION WITH MACHINE-TO-MACHINE NETWORKS AND SMART PHONES, U.S. application Ser. No. 15/521,871 TEMPORAL PROCESSES FOR AGGREGATING MULTI DIMENSIONAL DATA FROM DISCRETE AND DISTRIBUTED COLLECTORS TO PROVIDE ENHANCED SPACE-TIME PERSPECTIVE, U.S. application Ser. No. 15/522,175 METHODS AND SYSTEMS FOR REMOTE SENSING WITH DRONES AND MOUNTED SENSOR DEVICES, and U.S. application Ser. No. 15/532,578 SWARM APPROACH TO CONSOLIDATING AND ENHANCING SMARTPHONE TARGET IMAGERY BY VIRTUALLY LINKING SMARTPHONE CAMERA COLLECTORS ACROSS SPACE AND TIME USING MACHINE-TO MACHINE NETWORKS.

In some embodiments, the device **400** further comprises an application **500** including user interface **501**. In some embodiments, application **500** runs on native device frameworks, and is available for download onto devices **400** running operating systems **422** such as Android and iOS.

FIG. **11**, FIG. **12**, and FIG. **13** illustrate user interface **501** in accordance with an exemplary embodiment of the present disclosure. In some embodiments, user interface **501** includes settings **502**, gallery or storage **504**, fire or switch **290**, and color pallet **506** including Spectral band selector slider **518**. In some embodiments, settings **502** opens a menu or table, such as the interface shown in FIG. **12**, of various options and customizable parameters to configured when taking a hyperspectral/multispectral image. Such options and parameters include Exposure time slider **508**, ISO slider **510**, notes area **512**, subject mode selector **514**, and remote drone control **516**. In some embodiments, Exposure slider **508** allows a user to adjust the exposure time of an image from $\frac{1}{3200}$ of a second to 30 seconds. ISO slider **510** adjusts the ISO of an acquired image. In some embodiments, ISO slider can be adjusted to values in between 50 and 12,800. Notes area **512** is configured to allow a user or application **500** to input various text, images, videos, and the like. Mode selector **514** allows a user to adjust an acquired image according to various uses cases of the imaging device **100**. In the exemplary embodiment, modes for agriculture and vegetation analysis, VEG, skin and medical analysis, SKIN, and other various uses are available for selection; however, the present discloser is not limited there to. Drone control **516** can be utilized in various embodiments where imaging device **100** is attached to a drone, or each imaging device in a plurality of imaging devices is attached to a respective drone in a plurality of drones. In such embodiments, swarm control and/or control of individual drone and respective devices can be manipulated through drone control **516**. Spectral band selector slider **518** allows a user to manipulate spectral bands of emitted light. In the present embodiment, spectral band selector slider is a standard RGB 256-point slider; however, in other embodiments slider **518** can incorporate other spectral bands of the electromagnetic spectrum including, but not limited to, infrared light and ultraviolet light. In some embodiments, these options can be automatically adjusted and optimized according to various environmental factors or can be manually adjusted by a user of the device **400**.

In some embodiments, such as the embodiments shown in FIG. **1**, FIG. **3**, and FIG. **11**, switch **290** is configured as a component of the mobile device **400**, such as a home button. In some embodiments, switch **290** is configured to implement, fire, or execute a method or non-transitory computer readable storage medium comprising one or more programs of the imaging device **100**. In some embodiments, the switch **290** is remoted activated. The remote activation can be achieved through a sensor, a plurality of sensors, an electronic communication, or a wireless transmission. Thus, a user can remotely operate the imaging device **100** from a distance. In some embodiments, such as the embodiment shown in FIG. **3**, switch **290** a physical mechanism disposed on an external surface of the housing **300**. In various embodiments, switch **290** can be configured as various ON/OFF mechanism such as a knob, a dial, a slide, and the like. In some embodiments, switch **290** is a power supply switch of the imaging device.

In some embodiments, the user interface **456** may include one or more soft keyboard embodiments. The soft keyboard embodiments may include standard (QWERTY) and/or non-standard configurations of symbols on the displayed icons.

Accordingly, a user interface according to an exemplary embodiment of the present disclosure achieves the advantages of allowing a user to optimize and customize generating a hyperspectral/multispectral image.

It should be appreciated that device **400** is only one example of a portable multifunction device, and that device **400** optionally has more or fewer components than shown in FIG. **2**, optionally combines two or more components, or optionally has a different configuration or arrangement of the components.

FIG. **3**, FIG. **4**, and FIG. **5** depict a front view of the imaging device **100** and the housing **300** according to various embodiments of the present disclosure.

Referring to FIG. **3**, the imaging device **100** includes an objective lens **210**. The objective lens **210** is disposed within the housing **300** and flush with a surface of the housing **300**. Thus, the objective lens **210** does not substantially extend past the given surface of the housing **300**. As illustrated in FIG. **3**, a plurality of light source sets **110** is attached or integrated into the housing **300**. Each respective light source set (**110**-A, **110**-B, **110**-C) in the plurality of light source sets **110** comprises a plurality of lights. Each plurality of lights is uniformly radially distributed about the objective lens **210**. In some embodiments, the plurality of light sets **110** form a circle about the objective lens **210**, however, the present disclosure is not limited thereto. For instance, in other embodiments each respective light source set (**110**-A, **110**-B, **110**-C) in the plurality of light source sets **110** can form a concentric circle about the objective lens **210**. In such embodiments, there can exist k light source sets (**110**-A, **110**-B, **110**-C, **110**-*i*, . . . , **110**-*k*) in the plurality of light source sets forming a maximum of k concentric circles about the objective lens **210**, where k is a maximum number of light source sets in the plurality of light source sets **110**. In various embodiments, the plurality of lights source sets can form a plurality of arc segments about the objective lens **210**. The arc segments can be uniform; however, the present disclosure is not limited there to so long as the plurality of light source sets are uniformly distributed about the objective lens **210**.

In some embodiments, the objective lens **210** is a component of the mobile device **400**; however, the present disclosure is not limited thereto. For instance, in some embodiments the objective lens **210** is a stand-alone device such as an auxiliary web camera. In various embodiments, the objective lens **210** is selected from the group consisting of a 3D binocular, a fiber optic, a fisheye lens, a macro lens, a microscopic lens, a normal lens, and a telephoto lens.

The type of objective lens and spacing of the plurality of light source sets varies greatly depending on application. For instance, an imaging device utilized for skin care and other small region of interest applications can have a region of interest ranging from 1 cm^2 to 10 cm^2 and a plurality of lights disposed with a diameter ranging in between 0.5 cm to 10 cm. An imaging device utilized for agriculture surveying and other large regions of interest applications care can have a region of interest ranging from 1 m^2 to hundreds of thousands of m^2 and a plurality of lights disposed with a diameter ranging in between 0.5 cm to 10 cm. In such large region of interest applications, a user may combine a plurality of imaging devices **100** into an array of imaging devices. In such an embodiment, the plurality of imaging devices form a plurality of light source sets, thus accomplishing the same objectives of a single imaging device of the present disclosure yet on a larger scale. Naturally, embodiments in between such micro and macroscopic regions of interest exist including Biometrics, materials analysis, materials detection, and the like. In some embodiments, the region of interest is any closed form shape (e.g., circular, elliptical, polygon, rectangular, etc.).

FIG. **6** depicts an embodiment of the present disclosure where imaging device **100** is integrated with mobile device **400**. In some embodiments, the plurality of light source sets, and thus the imaging device, is flush with a surface of the mobile device. The term “flush”, as used herein, is defined as a surface of a first component and a same respective surface of a second component to have a distance or level separating the first component and the second component to be 0.0 cm, within a tolerance of 50 within a tolerance of 0.1 mm, within a tolerance of 0.1 cm, or within a tolerance of 0.25 cm. In some embodiments, the same respective surface of the second component is coplanar to the surface of the first component. An imaging device considered to be flush with a mobile device can be either internally disposed within the mobile device or integrated with the mobile device.

Referring to FIG. **4**, in some embodiments each light source set (**110-1**, **110-2**, **110-3**, **110-4**) in the plurality of light source sets **110** contains a single light source. In the present embodiment, each single light source has a predetermined spectral range or wavelength. As such, each light source set (**110-1**, **110-2**, **110-3**, **110-4**) in the plurality of light source sets **110** emits a unique spectral range or wavelength. Thus, the light source set **110-1** emits a first spectral range or wavelength, the light source **110-2** emits a second spectral range or wavelength, the light source **110-3** emits a third spectral range or wavelength, and the light source **110-4** emits a fourth spectral range or wavelength. For example, the light source set **110-1** can emit red light, the light source set **110-2** can emit blue light, the light source set **110-3** can emit green light, and the light source set **110-4** can emit infrared light; however, the present invention is not limited thereto. In some embodiments, each light source set **110** is characterized by (e.g., emits) a predetermined spectral range or wavelength. In some embodiments, each light source set **110** is characterized by a different spectral range or wavelength that does not overlap with the spectral range or wavelength of any of the other light source set **110**. In some embodiments, each light source set **110** is characterized by a different spectral range that does not overlap with the spectral range of any of the other light source set **110**. In some embodiments, each light source set **110** is characterized by a different spectral range and the different spectral range of at least one light source set **110** partially overlaps with the spectral range of another light source set **110**. For instance, in some embodiments, a first source set **110** is characterized by a spectral range from x to y nm and a second first source set **110** is characterized by a spectral range from w to z nm, where w is between x and y.

In various embodiments, only a red spectral band light source set, a green light spectrum band light source set, and a blue light spectrum band light source set exists in the plurality of light source sets. In such embodiments, the imaging device further comprises a color detector. The color detector is configured to detect across the electromagnetic spectrum, specifically the visible light band in the present embodiment, and senses excitation light reflected from a region of interest. Red, green, and blue light wavelengths bands are distinct and can easily be differentiated from each other, thus the detector may detect a multi-modal distribution of light. The multi-modal distribution can be analyzed to determine the specific of wavelengths or spectral bands of light detected by the color detector. Thus, a single image can be captured, analyzed, and processes to produce a hyperspectral/multispectral image.

The embodiment shown in FIG. **4** depicts four light source sets (**110-1**, **110-2**, **110-3**, **110-4**); however, the present disclosure is not limited thereto. In a further embodiment, the imaging device **100** includes k sets of light sources sets (**110**-A, **110**-B, **110**-*i*, . . . , **110**-*k*) in the plurality of light source sets **110**, where k is a positive integer greater than or equal to two. In some embodiments, the imaging device **100** includes two light source sets in the plurality of light source sets **110**. In another embodiment, the imaging device **100** includes four light source sets in the plurality of light source sets **110**. In yet embodiment, the imaging device **100** include five light source sets in the plurality of light source sets, six light source sets in the plurality of light source sets, seven light source sets in the plurality of light source sets, eight light source sets in the plurality of light source sets, nine light source sets in the plurality of light source sets, ten light source sets in the plurality of light source sets, eleven light source sets in the plurality of light source sets, or twelve light source sets in the plurality of light source sets.

In some embodiments, various light source sets in the plurality of light source sets may share or overlap within a spectral range.

In specific embodiments, there exists a plurality of bandpass filters substantially limiting the light emitted by the plurality of light source sets **110**. Each light source in the first light source set **110-1** is filtered by a different bandpass filter in a first plurality of bandpass filters. Each bandpass filter in the first plurality of bandpass filters limits light emission to the first spectral range. Additionally, each light source in the second light source set **110-2** is filtered by a different bandpass filter in a section plurality of bandpass filters. Each bandpass filter in the plurality of bandpass filters limits light emission to the spectral range. The same holds true for the third light source set **110-3**, and the fourth light source set **110-4** up to the k^{th} light source set.

In some embodiments, the plurality of bandpass filters includes at least one longpass filter. In some embodiments, the plurality of bandpass filters includes at least one shortpass filter.

In an exemplary embodiment of the present implementation, the plurality of light source sets each contains a single full spectrum light source. However, a different bandpass filter is disposed over each respective light source set in the plurality of light source sets. The pass bands of filters used in such implementations are based on the identity of the spectral bands to be imaged for created of the digital image.

In some embodiments, the unique spectral range of each light source set is defined by a given type of light source disposed therein. In some embodiments, the plurality of light source sets comprises full spectrum light sources. In another embodiment, the plurality of light source sets comprises partial spectrum light sources including, but not limited to, halogen light sources, tungsten light sources, fluorescent light sources, and/or a combination thereof. In some embodiments, the plurality of light source sets comprises stable LEDs, tunable LEDs, or a combination thereof. In some embodiments, the plurality of light source sets comprises 405±10 nm light sources, 475±10 nm light sources, 520±10 nm light sources, 570±10 nm light sources, 630±10 nm light sources, 660±10 nm light sources, 740±10 nm light sources, 890 nm±10 light sources, or a combination thereof. In some embodiments, the plurality of light source sets comprises 405±20 nm light sources, 475±20 nm light sources, 520±20 nm light sources, 570±20 nm light sources, 630±20 nm light sources, 660±20 nm light sources, 740±20 nm light sources, 890 nm±20 light sources, or a combination thereof. In some embodiments, the plurality of light source sets comprises 405±5 nm light sources, 475±5 nm light sources, 520±5 nm light sources, 570±5 nm light sources, 630±5 nm light sources, 660±5 nm light sources, 740±5 nm light sources, 890 nm±5 light sources, or a combination thereof. In some embodiments, the plurality of light source sets comprises light sources which vary in wavelength with time or a predetermined function.

In some embodiments, the plurality of light source sets comprises a laser light source or a plurality of laser light sources. In some embodiments, a plurality of spot readings is simultaneously compiled for each laser light source in plurality of laser light sources. Laser light sources are particularly useful when a subject or region of interest is a solid color.

In some embodiments, the plurality of light source sets comprises non-polarized light sources, polarized light sources, or a combination thereof. In some embodiments, the polarized light sources include linear polarized sources, cross polarized sources, circular polarized sources, or a combination thereof. In some embodiments, rather than emitting polarized light, the imaging device **100** is configured to received polarized light.

In some embodiments, the first spectral range and the k^{th} spectral range overlap but do not coexist. In other embodiments, the first spectral range and the k^{th} spectral range overlap. In some embodiments, each spectral range in the plurality of spectral ranges is engineered for a specific predetermined wavelength or spectral range.

In some embodiments, emitted light has a radiant flux in between 5 milliwatts (mW) and 95 mW. In some embodiments, emitted light has a radiant flux in between 10 mW and 75 mw. In some embodiments, emitted light has a radiant flux in between 1 mW and 100 mW. In some embodiments, emitted light has a radiant flux in between 50 mW and 1000 mW. In some embodiments, emitted light has a radiant flux in between 0.01 mW and 100 mW.

In one implementation, particularly skin care uses, the imaging device **100** is configured to collect a set of images, where each image is collected at a discrete spectral band and time period, and the set of images comprises images collected at any two or more, any three or more, any four or more, any five or more, or all of the set of discrete spectral bands having central wavelengths {475±10 nm, 520±10 nm, 570±10 nm, 630±10 nm, 660±10 nm, 740±10 nm, and 890 nm±10}. In some embodiments of this implementation, a first light source set in the plurality of light source sets emits light which has a wavelength of 630±10 nm with an intensity of 1000 mcd for 2 ms, a second light source set in the plurality of light source sets emits light which has a wavelength of 520±10 nm with an intensity of 2000 mcd for 4 ms, and a third light source set in the plurality of light source sets emits light which has a wavelength of 405±10 nm with an intensity of 1000 mcd for 8 ms. In some embodiments of this implementation, a first light source set in the plurality of light source sets emits light which has a wavelength of 630±20 nm with an intensity of 1000 mcd for 2 ms, a second light source set in the plurality of light source sets emits light which has a wavelength of 520±20 nm with an intensity of 2000 mcd for 4 ms, and a third light source set in the plurality of light source sets emits light which has a wavelength of 405±20 nm with an intensity of 1000 mcd for 8 ms. In some embodiments of this implementation, a first light source set in the plurality of light source sets emits light which has a wavelength of 630±5 nm with an intensity of 1000 mcd for 2 ms, a second light source set in the plurality of light source sets emits light which has a wavelength of 520±5 nm with an intensity of 2000 mcd for 4 ms, and a third light source set in the plurality of light source sets emits light which has a wavelength of 405±5 nm with an intensity of 1000 mcd for 8 ms. The above exposure times are not meant to significantly limit the present disclosure. For instance, in some embodiments each exposure time can vary by ±1 ms.

In another embodiment of the present implementation, a first light source set in the plurality of light source sets emits light which has a wavelength of 475±10 nm with a radiant flux of 30 mW, a second light source set in the plurality of light source sets emits light which has a wavelength of

570±10 nm with a radiant flux of 5 mW, a third light source set in the plurality of light source sets emits light which has a wavelength of 660±10 nm with a radiant flux of 9 mW, a fourth light source set in the plurality of light source sets emits light which has a wavelength of 740±10 nm with a radiant flux of 95 mW, and a firth light source set in the plurality of light source sets emits light which has a wavelength of 890±10 nm with a radiant flux of 40 mW. In a further embodiment, each of the above wavelengths may further vary by ±5 nm or ±10 nm.

In another embodiment, such as the embodiments shown in FIG. **5** and FIG. **7**, the plurality of light source sets **110** comprise a plurality of clusters comprising the plurality of light source sets (**110**-A, **110**-B, **110**-C, . . . , **110**-*k*). In such an embodiment, when each light source set (**110**-A, **110**-B, **110**-C, . . . , **110**-*k*) is fired, the entire uniform radial distribution of lights can be illuminated. In other embodiments, unfirmly distributed regions of the imaging device can be illuminated.

Referring to FIG. **8**, there can exist a plurality of light source sets (**110-1**, **110-2**, **110-3**) in the plurality of light source sets **110**. Each light source set (**110-1**, **110-2**, **110-3**) in the plurality of light source sets **110** can consists of n light sources, where n is a positive integer. In the present embodiment, each light source set (**110-1**, **110-2**, **110-3**) comprises a plurality of lights (**110**-*i*-A, **110**-*i*-B, **110**-*i*-C, **110**-*i*-*n*). As such, each plurality of light sources of a respective light source set (**110-1**, **110-2**, **110-3**) in the plurality of light source sets **110**, is disposed with θ_1 degrees of separation to another plurality of light sources of the respective light source set (**110-1**, **110-2**, **110-3**) in the plurality of light source sets **110**, where

$$\theta_1 = \frac{360}{n}.$$

For example, in the present exemplary embodiment, each light source set (**110-1**, **110-2**, **110-3**) contains four plurality of light sources (e.g., there exist four iterations of **110-1**), thus 90° of separation between each light source of a respective light source set.

Furthermore, in some embodiments, each plurality of lights (**110**-*i*-A, **110**-*i*-B, **110**-*i*-C, . . . , **110**-*i*-*n*) of a respective light source set (**110-1**, **110-2**, **110-3**, . . . , **110**-*i*, **110**-*k*) is arranged with θ_2 degrees of separation, where

$$\theta_2 = \frac{360}{kn},$$

and k is a total number of light source sets, from an adjacent plurality of light sources of a different light source set in the plurality of light source sets. For example, in the present embodiment, there are three total light source sets (**110-1**, **110-2**, **110-3**) each of which contains four plurality of lights. Thus, each plurality of lights of the respective light source set in the plurality of light source sets is arranged with 30° of separation from an adjacent plurality of lights of a different light source set in the plurality of light source sets.

In some embodiments, lights sources of each respective light source set in the plurality of light source sets are disposed at a same location. In such embodiments a theoretical θ_2 is zero.

The above spatial relationships ensure that a uniform light distribution pattern is emitted towards a subject while minimizing adverse luminance and shadow effects.

In some implementations, each respective light source of a respective light source set (e.g., **110-1**-A, **110-2**-A, **110-3**-A) includes a unique discrete spectral range or wavelength; however, the present disclosure is not limited thereto.

In some embodiments, battery **240**, power management circuit **260**, and communication interface **280** are disposed within the housing **300**. In some embodiments, the battery **240** is a rechargeable battery.

In some embodiments, the communication interface **280** comprises a wireless signal transmission element and instructions are sent in accordance with a hyperspectral/multispectral imaging method by the wireless signal transmission element. In various embodiments, wireless signal transmission element is selected from the group consisting of a Bluetooth transmission element, a ZigBee transmission element, and a Wi-Fi transmission element.

In one implementation, the communication interface **280** comprises a first communications interface **280**. The imaging device **100** is coupled to the mobile device **400**, thereby bringing the first communications interface **280** in direct physical and electrical communication with a second communication interface of the mobile device **400**, thereby enabling instructions to be sent directly to the second communications interface from the first communications interface **280** in accordance with a hyperspectral/multispectral imaging method.

As mentioned above, conventional hyperspectral/multispectral imaging devices require high-end optics which can costs tens of thousands of dollars per device. Accordingly, the present disclosure can be designed using generic, off the shelf components. For example, an embodiment of the present disclosure can comprise a NeoPixel—12×5050 RGB LED with Integrated Drivers, an Adafruit Pro Trinket—5 V 16 MHz controller, an Adafruit Bluefruit LE UART Friend—Bluetooth Low Energy (BLE) communication interface, an Adafruit Pro Trinket Lilon/LiPoly Backpack Add-on power management system, and an ON-OFF Power Button/Pushbutton Toggle Switch, (Adafruit Industries, New York, N.Y.). Additionally, a 3.7 V 520 mAh Lithium Polymer rechargeable DV 603030 1.92 wh 14F2B BPI battery may be purchased (Amazon.com, Inc, Seattle, Wash.). Furthermore, custom LEDs are readily available from various manufacturers, (Marktech Optoelectronics, Lathan, N.Y.).

The imaging device **100** also includes a controller **220**. The controller **220** comprises at least one executable program non-transiently stored therein and is configured to control at least the plurality of light source sets **110**. In some embodiments, the controller **220** is a component of the mobile device **400**; however, the present disclosure is not limited thereto.

FIG. **10** collectively illustrates a flow chart of methods for imaging discrete wavelength bands using a device in accordance with an embodiment of the present disclosure. In the flow chart, the preferred parts of the methods are shown in solid line boxes whereas optional variants of the methods, or optional equipment used by the methods, are shown in dashed line boxes. As such, FIG. **10** illustrates methods for performing a hyperspectral/multispectral regime. The methods are performed at a device (e.g., mobile device **400**) comprising one or more processors, memory storing one more programs for execution by the one or more processors, an objective lens, a two-dimensional pixelated detector in optical communication with the objective lens, and i light source sets, the instructions comprising, for each integer i in the set {1, . . . , k}, wherein k is a positive integer.

As mentioned above, in various embodiments the imaging device **100** is attached to the mobile device **400**. The one or more programs singularly or collectively execute the method (**1002**).

In some embodiments, the objective lens is selected from the group consisting of a 3D binocular, a fiber optic, a fisheye lens, a macro lens, a microscopic lens, a normal lens, and a telephoto lens (**1004**)

In some embodiments, the two-dimensional pixelated detector is selected from the group consisting of a charge-coupled device (CCD), a complementary metal-oxide-semiconductor (CMOS), a photo-cell, and a focal plane array (**1006**).

In some embodiments, the mobile device is selected from the group consisting of a smart phone, a personal digital assistant (PDA), an enterprise digital assistant, a tablet computer, and a digital camera (**1008**).

In accordance with the method, the one or more programs singularly or collectively instruct a k^{th} plurality of lights uniformly radially distributed about the objective lens (e.g., objective lens **210** of FIG. **2**) in the k^{th} light source set to fire for a k^{th} time period while not firing any other light source set in the plurality of light source sets (**1010**).

In some embodiments, the instructing the first light source set to fire instructs the kth light source set to fire for no longer than 100 ms, no longer than 8 ms, no longer than 4 ms, or no longer than 2 ms (**1012**).

In accordance with the method, the one or more programs singularly or collectively instruct the two-dimensional pixelated detector to collect light from the objective lens during all or a portion of the k^{th} predetermined time period, thereby forming at least one digital image (**1014**).

In some embodiments, the at least one digital image is a single digital image (**1016**).

In some embodiments, a separate image is formed at each instance of the instructing **1010** (**1018**).

In some embodiments, the one or more programs singularly or collectively combine each separate digital image formed during the respective instances of the instructing **1010** into a single hyperspectral/multispectral image.

FIG. **14**A through FIG. **14**E illustrate various images and stages of image processing according to an exemplary embodiment of the present disclosure. In the present exemplary embodiment, the imaging device of the present disclosure is utilized for instantaneous wrinkle detection; however, the present disclosure may also be utilized for time lapse utilizations and the like. FIG. **14**A illustrates an RGB image of a subject capture by the imaging device of the present disclosure. The image of FIG. **14**A is then processed into the images of FIG. **14**B and FIG. **14**C, each of which comprise a discrete spectral band. Such processing can include 16 bit TIFF. The images of FIG. **14**B and FIG. **14**C are subsequently transformed to produce the image of FIG. **14**D. Additional analysis and layer of the previous images of FIG. **14**A to FIG. **14**D are utilized to produce a final image of FIG. **14**E. In the present embodiment, in order to detect and differentiate wrinkles, various parameters are considered including, but not limited to, total area per wrinkle which is a number of pixels classified as a wrinkle, percent area as wrinkle vs total area of a given region of interest, average length of a feature, average width of a feature, and type classification (e.g., fine, medium, coarse). The above are conducted through applications of advanced remote sensing techniques, custom detection algorithms, and scientific calibration protocols. Such applications allow automated generated output on scale through an advanced workflow architecture incorporating advanced spatial, spectra and temporal components. The images are rendered and adjustable using false color schematics or hybrid overlay views.

FIG. **15**A illustrates a lighting device **1500** according to an exemplary embodiment of the present disclosure. The lighting device **1500** is substantially ring-shaped and comprises a plurality of packages **1502**. Each package **1502** is configured to host (e.g., for attaching, fastening) a plurality of light components such as light **110**-A, light **110**-B, etc. disclosed herein. In some embodiments, each package is configured such that it can be easily adjusted to host different light components. For instance, each package **1502** can host five light components **110**-A, **110**-B, **110**-C, **110**-D, and **110**-E as illustrated in FIG. **15**A, or host five light components **110**-**1***a*, **110**-**1***b*-**1**, **110**-**1***b*-**2**, **110**-**1***c*, and **110**-**2***a* as illustrated in FIG. **15**B, where one or more of light components **110**-**1***a*, **110**-**1***b*-**1**, **110**-**1***b*-**2**, **110**-**1***c*, and **110**-**2***a* are different than light components **110**-A, **110**-B, **110**-C, **110**-D, and **110**-E.

FIG. **15**C and FIG. **15**D illustrate a lighting device **1500** according to another exemplary embodiment of the present disclosure. The lighting device **1500** comprises a plurality of packages **1502** each configured to host (e.g., for attaching, fastening) a plurality of light components such as light **110**-A, light **110**-B, etc. disclosed herein. Like the lighting device illustrated in FIG. **15**A and FIG. **15**B, in some embodiments, each package in this embodiment is configured such that it can be easily adjusted to host different light components. For instance, each package **1502** can host five light components **110**-A, **110**-B, **110**-C, **110**-D, and **110**-E as illustrated in FIG. **15**D, or host five light components **110**-A, **110**-B-**1**, **110**-B-**2**, **110**-B-**3** and **110**-B-**4** as illustrated in FIG. **15**E and FIG. **15**F, where light components **110**-B-**1**, **110**-B-**2**, **110**-B-**3** and **110**-B-**4** are the same as light component **110**-B.

While each package in FIG. **15**A to FIG. **15**F is shown with five light components, it should be note that the number of light components hosted by each package is not limited to five. The number of light components hosted by each package can be smaller than five as illustrated in FIG. **3** or greater than five as illustrated in FIG. **5**.

Light components can differ from each other in terms of type, shape, size, light wavelength, light intensity, or the like. In some cases, the effectiveness of different light components (e.g., semiconductor dies) varies largely with luminous intensity differences of multiple orders of magnitude. Those differences can to some degree be compensated by implementing multiple light components of the same spectral range to match the effectiveness of another, since lumens add up.

In some embodiments, the lighting device comprises J light source sets (i.e., each package comprises J light components) for emitting light of K spectral ranges. J is a positive integer of three or greater, and K is a positive integer smaller than J. Each spectral range is different than any other spectral range in the K spectral ranges. For each respective k^{th} spectral range in the K spectral ranges, the J light source sets comprise corresponding j_k light source set or sets, wherein j_k is a positive integer of one or greater, and $\Sigma_{k=1}^{K} j_k = J$. As such, at least for one specific spectral range in the K spectral ranges, there are multiple light components in each package that emit light of this specific spectral range. For instance, by way of example, FIG. **15**B illustrates two light components **110**-**1***b*-**1** and **110**-**1***b*-**2**, within each package **1502**, that emit light of the same spectral range. As another example, FIG. **15**F illustrates four light components

10-B-1, 110-B-2, 110-B-3 and 110-B-4, within each package 1502, that emit light of the same spectral range.

In some embodiments, two or more light source sets in the J light source sets emit light that is substantially limited to a first spectral range, and one or more light source sets in the J light source sets emit light that is substantially limited to a second spectral range other than the first spectral range. For instance, by way of example, FIG. 15F illustrates four light source sets (i.e., one set comprising light component 10-B-1 of each package, one set comprising light component 110-B-2 of each package, one set comprising light component 110-B-3 of each package, and one set comprising light component 110-B-4 of each package) emit light that is substantially limited to a spectral range, and one light source set (e.g., the set comprising light component 110-A of each package) emits light that is substantially limited to another different spectral range.

In some embodiments, one or more light source sets in the J light source sets emit light that is substantially limited to a third spectral range other than the first and second spectral ranges. For instance, by way of example, FIG. 15B illustrates two light source sets (i.e., one set comprising light component 110-1*b*-1 of each package and one set comprising light component 110-1*b*-2 of each package) emit light that is substantially limited to a spectral range, one light source set (e.g., the set comprising light component 110-1*a* of each package) emits light that is substantially limited to another different spectral range, and one light source set (e.g., the set comprising light component 110-1*c* of each package or the set comprising light component 110-2*a* of each package) emits light that is substantially limited to still another different spectral range.

In some embodiments, a collective lighting intensity produced by the two or more light source sets that emit light substantially limited to the first spectral range and a collective lighting intensity produced by the one or more light source sets that emit light substantially limited to the second spectral range are substantially the same. For instance, in some embodiments, the collective lighting intensity produced by the four light source sets comprising light components 10-B-1, 110-B-2, 110-B-3 and 110-B-4 of each package is substantially the same as the collective lighting intensity produced by the one light source set comprising light component 110-A of each package.

In some embodiments, a collective lighting intensity produced by the two or more light source sets that emit light substantially limited to the first spectral range, a collective lighting intensity produced by the one or more light source sets that emit light substantially limited to the second spectral range, and a collective lighting intensity produced by the one or more light source sets that emit light substantially limited to the third spectral range are substantially the same. For instance, in some embodiments, the collective lighting intensity produced by the two light source sets comprising light components 110-1*b*-1 and 110-1*b*-2 of each package, the collective lighting intensity produced by the one light source set comprising light component 110-1*a* of each package, and the collective lighting intensity produced by the one light source set comprising light component 110-1*c* or 110-2*a* of each package are substantially the same.

In some embodiments, a collective lighting intensity produced by the two or more light source sets that emit light substantially limited to the first spectral range is between 500 micro-candela to 1500 micro-candela.

In some embodiments, the light components are configured to maximize the spectral response in the desired spectral range or ranges of a region of interest (ROI). For instance, the specifications of the light components (e.g., spectral position and intensity) can be adjusted to maximize the spectral response in the desired spectral range or ranges. In some embodiments, the first spectral range is selected in accordance with an absorption spectra of a first chromophore and the second spectral range is selected in accordance with an absorption spectra of a second chromophore.

A light component can emit near infrared light, visible light, ultraviolet light, or other light, and the emitted light can be of a narrow spectral band or a continuous spectral range. For instance, in some embodiments, light components 110-1*a*, 110-1*b* and 110-1*c* in FIG. 15B emit near infrared light whereas light component 110-2*a* emits visible light of a continuous spectral range. Each of light components 110-1*a*, 110-1*b* and 110-1*c* in FIG. 15B emits near infrared light of a different narrow spectral band.

In some embodiments, the lighting device 1500 comprise light components emitting light that is substantially limited to 305±10 nm, 335±10 nm, 355±10 nm, 375±10 nm, 405±10 nm, 475±10 nm, 520±10 nm, 570±10 nm, 630±10 nm, 660±10 nm, 740±10 nm, 890 nm±10 nm, or a combination thereof. the lighting device 1500 comprise light components emitting light that are substantially limited to 405±20 nm, 475±20 nm, 520±20 nm, 570±20 nm, 630±20 nm, 660±20 nm, 740±20 nm, 890 nm±20 light sources, or a combination thereof. In some embodiments, the lighting device 1500 comprise light components emitting light that is substantially limited to 405±5 nm, 475±5 nm, 520±5 nm, 570±5 nm, 630±5 nm, 660±5 nm, 740±5 nm, 890 nm±5 light sources, or a combination thereof. In some embodiments, the first spectral range is 305 nanometers (nm) 10 nm to 890 nm±10 nm and the second wavelength band is 305 nm±10 nm to 890 nm 10 nm.

In some embodiments, the ROI comprises a human skin or a human face. The spectral response of human skin is mainly influenced by two major chromophores: melanin and hemoglobin. In some embodiments, the first spectral range is selected in accordance with an absorption spectra of a first chromophore (e.g., one of melanin and hemoglobin) and the second spectral range is selected in accordance with an absorption spectra of a second chromophore (e.g., the other melanin and hemoglobin).

The lighting device 1500 can be used or integrated with the imaging devices or mobile devices disclosed herein. In some embodiments, the lighting device 1500 is attached or integrated with the housing 300. In a preferable embodiment, each respective light source set in the J light source sets comprises a plurality of lighting components that is uniformly radially distributed about the objective lens of the imaging device.

In some embodiments, each light source set in the J light source sets consists of n lighting components, wherein n is a positive integer of value two or greater, and each lighting component of a respective light source set is arranged with θ_1 degrees of separation to another lighting component of the respective light source set, wherein

$$\theta_1 = \frac{360}{n}.$$

Operation of the J light source sets and the detector of the imaging device can be controlled by a controller in which at least one program is non-transiently stored. The at least one program is executable by the controller, and when executed, causes the controller to perform the methods disclosed herein.

For instance, FIG. **16** illustrates a method **1600** performed at an imaging device comprising a detector, a controller, and J light source sets for emitting light of K spectral ranges, wherein J is a positive integer of three or greater and K is a positive integer smaller than J. Each spectral range is different than any other spectral range in the K spectral ranges. For each respective k^{th} spectral range in the K spectral ranges, the J light source sets comprise corresponding j_k light source set or sets, wherein j_k is a positive integer of one or greater, and $\Sigma_{k=1}^{K} j_k = J$. At least one program is non-transiently stored in the controller and executable by the controller, causing the controller to perform the method **1600**.

In some embodiments, for each integer $k \in \{1, \ldots, K\}$, the method **1600** comprises: (A) concurrently firing lighting components of the j_k light source set or sets in the J light source sets for a k^{th} predetermined time period (Block **1602**); and (B) collecting, using the detector, light during all or a portion of the k^{th} predetermined time period, thereby forming at least one digital image (Block **1604**).

For instance, in some embodiments, two or more light source sets in the J light source sets emit light that is substantially limited to a first spectral range, and one or more light source sets in the J light source sets emit light that is substantially limited to a second spectral range other than the first spectral range. In such embodiments, the method **1600** comprises: (i) concurrently firing the two or more light source sets that emit light substantially limited to the first spectral range while not firing any other light source set in the J light source sets; (ii) collecting light from the objective lens over a first time period using the detector; (iii) concurrently firing the one or more light source sets that emit light substantially limited to the second spectral range while not firing any other light source set in the J light source sets; and (iv) collecting light from the objective lens over a second time period using the detector, thereby forming at least one digital image. In some embodiments, one or more light source sets in the J light source sets emit light that is substantially limited to a third spectral range other than the first and second spectral ranges. In such embodiments, the method **1600** further comprises: (v) concurrently firing the one or more light source sets that emit light substantially limited to the third spectral range while not firing any other light source set in the J light source sets; and (vi) collecting light from the objective lens over a third time period using the detector.

FIG. **17**A, FIG. **17**B and FIG. **17**C collectively illustrate a flow chart of an exemplary method **1700** for reducing or eliminating ambient light effect. The method **1700** can be performed at an imaging device including but not limited to devices disclosed here. For instance, in some embodiments, the method **1700** is performed at an imaging device comprising one or more light source sets, a detector and a controller. At least one program is non-transiently stored in the controller and executable by the controller. When executed, the at least one program causes the controller to perform the method **1700**.

To reduce or eliminate the effect of ambient light, the method **1700** implements a subtraction procedure that acquires two images of the ROI, one with illumination light and one with only ambient light, and then subtracts the image with only ambient light from the image with illumination light. In a preferable embodiment, the illumination light has an intensity greater the that of the ambient light. In some embodiments, for instance when there are spatial offsets between the two images, the method **1700** also performs one or more automated registration procedures to correct the spatial offsets.

In some embodiments, the method **1700** comprises: (A) acquiring a reference image of a region of interest (ROI) by using the detector to collect light over a reference time period while the ROI is not exposed to any light emitted from the one or more light source sets, wherein the reference image comprises an array of pixels each corresponding to a sub-region in an array of sub-regions of the ROI (Block **1702**). That the ROI not exposed to any light emitted from the one or more light source sets can be achieved, by not firing any of the one or more light source sets, by blocking the pathway of the light from the one or more light source sets to the ROI, or the like.

The method **1700** comprises: (B) firing a first light source set while not firing any other light source set in the one or more light source sets, wherein the first light source set in the one or more light source sets emits light that is substantially limited to a first spectral range (Block **1704**). In a preferable embodiment, the light emitted from each light source set in the one or more light source sets has an intensity higher than the light from the ambient. In some embodiments, the first time period is substantially the same as the reference time period. In some embodiments, for instance when the imaging device further comprises an objective lens in optical communication with the detector, the first light source set in the one or more light source sets comprises a plurality of lighting components that is radially distributed about the objective lens of the imaging device.

The method **1700** also comprises (C) acquiring a first target image of the ROI by using the detector to collect light over a first time period while the ROI is exposed to the light emitted from the first light source set, wherein the first target image comprises an array of pixels each corresponding to a sub-region in the array of sub-regions of the ROI (Block **1706**). In some embodiments, the detector comprises a two-dimensional pixelated detector such as the two-dimensional pixelated detector **473** disclosed herein.

The method **1700** further comprises: (D) compensating the first target image of the ROI using the reference image of the ROI, thereby generating a first compensated image of the ROI, wherein each respective pixel in the array of pixels of the first target image is compensated using the corresponding pixel in the array of pixels of the reference image (Block **1710**). In some embodiments, each respective pixel in the array of pixels of the first target image is compensated by subtracting, from an intensity value at the respective pixel, an intensity value at the corresponding pixel in the array of pixels of the reference image multiplied by a ratio of the first time period over the reference time period.

The method **1700** can implement alternative, additional or optional procedures. For instance, in some embodiments (e.g., when there are spatial offsets between the reference image and the first target image), prior to the compensating (D), the method **1700** performs a step of: (E) co-registering the reference image and the first target image of the ROI (Block **1708**).

In some embodiments, the method **1700** performs reduction or elimination of ambient light effect for images acquired at one or more other spectral ranges. For instance, in some embodiments, the method **1700** performs the steps of: (F) firing a second light source set while not firing any other light source set in the one or more light source sets, wherein the second light source set in the one or more light source sets emits light that is substantially limited to a second spectral range, and the second spectral range that is different than the first spectral range (Block **1712**); (G) acquiring a second target image of the ROI by using the detector to collect light over a second time period while the ROI is exposed to the light emitted from the second light source set, wherein the second target image comprises an array of pixels each corresponding to a sub-region in the array of sub-regions of the ROI (Block **1714**); and (H) compensating the second target image of the ROI using the reference image of the ROI, thereby generating a second compensated image of the ROI, wherein each respective pixel in the array of pixels of the second target image is compensated using the corresponding pixel in the array of pixels of the reference image (Block **1716**). In some embodiments, each respective pixel in the array of pixels of the second target image is compensated by subtracting, from an intensity value at the respective pixel, an intensity value at the corresponding pixel in the array of pixels of the reference image multiplied by a ratio of the second time period over the reference time period. In some embodiments, the second time period is substantially the same as the first time period and/or the reference time period.

FIG. **18**A and FIG. **18**B collectively illustrate a flow chart of another exemplary method **1800** for reducing or eliminating the effect of ambient light. The method **1800** can be performed at an imaging device including but not limited to devices disclosed here. For instance, in some embodiments, the method **1800** is performed at an image device comprising a detector, a controller, and J light source sets for emitting light of K spectral ranges, wherein each spectral range is different than any other spectral range in the K spectral ranges. J and K are positive integrals. For each respective k^{th} spectral range in the K spectral ranges, the J light source sets comprise corresponding j_k light source set or sets, wherein j_k is a positive integer of one or greater, and $\Sigma_{k=1}^{K} j_k = J$. In some embodiments, K equals to J. That is, for each respective k^{th} spectral range in the K spectral ranges, there is one single corresponding light source set in the J light source sets. In some embodiments, J is a positive integer of three or greater and K is a positive integer smaller than J. That is, for at least one spectral range in the K spectral ranges, there are multiple corresponding light source sets in the J light source sets. For instance, in some embodiments, two or more light source sets in the J light source sets emit light that is substantially limited to a first spectral range, and one or more light source sets in the J light source sets emit light that is substantially limited to a second spectral range other than the first spectral range. In some embodiments, one or more light source sets in the J light source sets emit light that is substantially limited to a third spectral range other than the first and second spectral ranges.

At least one program is non-transiently stored in the controller and executable by the controller. When executed, the at least one program causes the controller to perform the method **1800** comprising: (A) acquiring a reference image of a region of interest (ROI) by using the detector to collect light over a reference time period while the ROI is not exposed to any light emitted from the one or more light source sets, wherein the reference image comprises an array of pixels each corresponding to a sub-region in an array of sub-regions of the ROI (Block **1802**). For each integer $k \in \{1, \ldots, K\}$, the method **1800** also includes: (B) concurrently firing lighting components of the j_k light source set or sets in the J light source sets while not firing any other light source set in the J light source sets (Block **1804**); (C) acquiring a respectively target image of the ROI by using the detector to collect light over a respective k^{th} target time period while the ROI is exposed to the light emitted from the j_k light source set or sets, wherein the respective target image comprises an array of pixels each corresponding to a sub-region in the array of sub-regions of the ROI (Block **1806**); and (D) compensating the respective target image of the ROI using the reference image of the ROI, thereby generating a respective compensated image of the ROI, wherein each respective pixel in the array of pixels of the respective target image is compensated using the corresponding pixel in the array of pixels of the reference image (Block **1810**). In some embodiments, each respective pixel in the array of pixels of the respective target image is compensated by subtracting, from an intensity value at the respective pixel, an intensity value at the corresponding pixel in the array of pixels of the reference image multiplied by a ratio of the respective k^{th} target time period over the reference time period.

The method **1800** can implement alternative, additional or optional procedures. For instance, similar to the method **1700**, in some embodiments (e.g., when there are spatial offsets between the reference image and the first target image), prior to the compensating (D), the method **1800** performs a step of: (E) co-registering the reference image and the respective target image of the ROI (Block **1808**). In some embodiments, the method **1800** further comprises: (F) combining each respective compensated image of the ROI generated using each respective light source set in the plurality of light source sets into a single hyperspectral/multispectral image (Block **1812**).

FIG. **19**A, FIG. **19**B and FIG. **19**C collectively illustrate a flow chart of an exemplary method **1800** for reducing or eliminating incidence angle and distance effect. The method **1900** can be performed at an imaging device including but not limited to devices disclosed here. For instance, in some embodiments, the method **1900** is performed at an imaging device comprising an objective lens, a light source adjacent to the objective lens, a detector in optical communication with the objective lens, and a controller. At least one program is non-transiently stored in the controller and executable by the controller. When executed, the at least one program causes the controller to perform the method **1900**.

Preferably, the light source is any substantially ring-shaped light sources or lighting devices disclosed herein. Since the light source is adjacent or surrounding the objective lens, the angle of projection is similar to the angle of a camera. As such, the method **1900** implements a normalization procedure to reduce or eliminate the brightness differences due to the incidence angle effect within an image. In some embodiments, the image data is normalized against data collected from a Lambertian surface at a selfie-like distance (e.g., between 0.5 to 2 feet).

To reduce or illuminate the distance effect, the method **1900** first implements 3D reconstruction procedures to create a 3D model. 3D reconstruction can be made from multiple images or from a single image. For instance, Jackson et al. 2017 discloses 3D reconstruction from a single image, entitled "Large Pose 3D Face Reconstruction from a Single Image via Direct Volumetric CNN Regression", which is hereby incorporated by reference in their entirety. The method **1900** then uses the 3D model to identify the depths of the scene, e.g., parts (sub-regions of the ROI) closer and further away with respect to the objective lens or a reference plane. Since parts are illuminated differently depending on the distance from the camera/light-source setup, parts that are further away appear less bright than parts that are closer to the objective lens. Those parts can then be linearly corrected in brightness, for instance, the pixel brightness levels can be adjusted to or based on the intensities of a pseudo flat surface.

In some embodiments, the method **1900** comprises: (A) acquiring a target image of a region of interest (ROI) by using the detector to collect light over a target time period while the ROI is exposed to light emitted from the light source, wherein the target image comprises an array of pixels each corresponding to a sub-region in an array of sub-regions of the ROI (Block **1902**). In some embodiments, the ROI is a face of a subject. In an embodiment, the ROI is a full face of a subject.

In a preferable embodiment, the light source comprises one or more light source sets, each light source set comprising a plurality of lighting components that is radially distributed about the objective lens. In some embodiments, the light source comprises J light source sets for emitting light of K spectral ranges, wherein each spectral range is different than any other spectral range in the K spectral ranges. For each respective k^{th} spectral range in the K spectral ranges, the J light source sets comprise corresponding j_k light source set or sets, wherein j_k is a positive integer of one or greater, and $\Sigma_{k=1}^{K} j_k = J$. Each light source set in the J light source sets comprises a plurality of lighting components that is radially distributed about the objective lens. In an embodiment, J is a positive integer of three or greater and K is a positive integer smaller than J.

The method **1900** also comprises: creating a three-dimensional model for the ROI using the target image of the ROI, wherein the three-dimensional model comprises a plurality of points, each comprising three spatial coordinates (Block **1908**). In some embodiments, the three-dimensional model for the ROI is created using a volumetric Convolutional Neural Network (CNN) that performs direction regression of a volumetric representation of the three-dimensional model from the target image.

The method **1900** further comprises: (C) determining a relative distance of each respective point in the plurality of points of the three-dimensional model with respect to the objective lens or with respect to a pseudo flat surface (Block **1910**); and (D) adjusting brightness levels of the three-dimensional model in accordance with the determined relative distance of each respective point in the plurality of points of the three-dimensional model (Block **1912**). In some embodiments, the brightness levels of the three-dimensional model are adjusted linearly in accordance with the relative distances. In an embodiment, the brightness levels of the three-dimensional model are adjusted based on intensity values at the pseudo flat surface. In another embodiment, the brightness levels of the three-dimensional model are adjusted to brightness values at the pseudo flat surface.

The method **1900** can implement alternative, additional or optional procedures. For instance, the method **1900** can implement the procedures to reduce or eliminate the ambient light effect. To do so, the method **1900** comprises: (E) compensating, prior to the creating (B), the target image of the ROI using a reference image of the ROI, thereby generating a compensated image of the ROI, wherein the reference image of the ROI is acquired by using the detector to collect light over a reference time period while the ROI is not exposed to any light emitted from the light source, wherein each respective pixel in an array of pixels of the target image is compensated using the corresponding pixel in an array of pixels of the reference image, and wherein the creating (B) is performed on the compensated target image (Block **1904**).

In some embodiments, prior to the creating (B) of the 3D model, the method **1900** implements procedures to correct incidence angle effect. For instance, in some embodiments, the method **1900** further comprises: (F) normalizing, prior to the creating (B), the target image of the ROI using a dataset collected from a Lambertian surface, thereby producing a normalized target image, wherein an intensity value of each respective pixel in the array of pixels of the target image is normalized by a corresponding intensity value in the dataset of the Lambertian surface, and wherein the creating (B) is performed on the normalized target image (Block **1906**). In an embodiment, the dataset of the Lambertian surface is collected with the Lambertian surface positioned at a distance of between 0.5 feet and 3 feet from the objective lens.

In some embodiments, the normalizing (F) is performed, subsequent the compensating (E), on the compensated target image.

ADDITIONAL EXEMPLARY EMBODIMENTS

Implementation 1: In some embodiments, the present disclosure provides a computer-implemented method of correcting a target image at a central controlling system. The method comprises: (A) using one or more computer-enabled imaging devices to collect image data of a region of interest by causing the one or more computer-enabled imaging devices to execute a method comprising: (i) obtaining a reference image of a region of interest in accordance with a first plurality of capture parameters at a first time using the one or more computer-enabled imaging devices, wherein the first plurality of capture parameters comprises a first subset of capture parameters, and a second subset of capture parameters different than the first subset of capture parameters; (ii) obtaining the target image of the region of interest in accordance with a second plurality of capture parameters at a second time using the one or more computer-enabled imaging devices, wherein the second plurality of capture parameters comprises the first subset of capture parameters, and a third subset of capture parameters different than both of the first subset of capture parameters and the second subset of capture parameters; and (iii) communicating to the central computer-system the reference image with the first plurality of capture parameters and the target image with the second plurality of capture parameters; and (B) at the central controlling system, the central controlling system having one or more processors and memory for storing one or more programs for execution by the one or more processors, executing the method of: (i) receiving the reference image with the first plurality of capture parameters and the target image with the second plurality of capture parameters from the one or more computer-enabled imaging devices; and (ii) using the first subset of capture parameters, the second subset of capture parameters, and the third subset of capture parameters to correct the target image against the reference image, thereby forming a corrected target image.

Implementation 2: In some embodiments, the computer-implemented method of Implementation 1, wherein an elapsed period of time between the first time of the obtaining the first image and the second time of the obtaining the second image is less than one second.

Implementation 3: In some embodiments, the computer-implemented method of Implementation 1, wherein the second subset of capture parameters comprise a first wavelength spectra of light at a first intensity, and the third subset of capture parameters comprise a second wavelength spectra of light at a second intensity.

Implementation 4: In some embodiments, the computer-implemented method of Implementation 3, wherein the using the capture parameters at the central controlling system comprises: evaluating the reference image to determine the first wavelength spectra, and determining the second wavelength spectra based on a difference between a predetermined wavelength spectra of the third subset of control parameters of the target image and the first wavelength spectra of the reference image.

Implementation 5: In some embodiments, the computer-implemented method of Implementation 3, wherein the second wavelength spectra comprises a predetermined wavelength spectra and the first wavelength spectra.

Implementation 6: In some embodiments, the computer-implemented method of Implementation 3, wherein the second intensity of light is greater than the first intensity of light.

Implementation 7: In some embodiments, the computer-implemented method of Implementation 3, wherein the using the capture parameters at the central controlling system comprises: evaluating a difference between the first wavelength spectra and the second wavelength spectra, and removing the difference between the first wavelength spectra and the second wavelength spectra from the target image, thereby forming the corrected target image.

Implementation 8: In some embodiments, the computer-implemented method of Implementation 1, wherein the first subset of capture parameters comprises a distance from the one or more computer-enabled imaging devices to the target of region and a tolerance of variation from the distance, and the using the capture parameters at the central controlling system comprises: evaluating a difference between a first tolerance of variation from the distance for the reference image and a second tolerance of variation from the distance for the target image, and offsetting the target image by the difference between the first tolerance and the second tolerance, thereby forming the corrected target image.

Implementation 9: In some embodiments, the computer-implemented method of Implementation 1, wherein the obtaining the reference image comprises forming a three-dimensional model of a portion of the region of interest, and

Implementation 10: In some embodiments, the computer-implemented method of Implementation 9, wherein the region of interest comprises a textured surface, and the using the capture parameters at the central controlling system comprises: evaluating the reference image for one or more variations in luminance caused by the textured surface, forming a digital map of the textured surface based on the evaluation of one or more variations in luminance, and applying the digital map of the textured surface to the target image, thereby forming the corrected target image.

Implementation 11: In some embodiments, the computer-implemented method of Implementation 10, wherein the digital map is a map of reflective properties of the textured surface.

Implementation 12: In some embodiments, the computer-implemented method of Implementation 10, wherein the applying the digital map corrects a luminance of the target image to form the corrected target image.

Implementation 13: In some embodiments, the computer-implemented method of Implementation 10, wherein: the evaluating the reference image for one or more variations in luminance forms an evaluation of a change in height of the textured surface, and the digital map is a map of the evaluated change in height of the textured surface.

Implementation 14: In some embodiments, the computer-implemented method of Implementation 10, wherein the digital map is a flattened replication of the textured surface, and the applying the digital map flattens the textured surface of the region of interest in the target image to form the corrected target image.

Implementation 15: In some embodiments, the computer-implemented method of Implementation 10, wherein the applying the digital map of the textured surface to the target image corrects a luminance of the target image based on a linear function, thereby forming the corrected target image.

Imaging devices of the present discloser enable a user to acquire a hyperspectral/multispectral image of a wide range of regions of interest, from small scale images such as pores on a person's face to large scale images such as farms and geological formations. Another advantage of the present invention is ability to increase the energy of a system by providing high illuminance in order to generate a high quality hyperspectral/multispectral image. Furthermore, the present disclosure can be provided at a reduced manufacturing costs.

For convenience in explanation and accurate definition in the appended claims, the terms "upper", "lower", "up", "down", "upwards", "downwards", "inner", "outer", "inside", "outside", "inwardly", "outwardly", "interior", "exterior", "front", "rear", "back", "forwards", and "backwards" are used to describe features of the exemplary embodiments with reference to the positions of such features as displayed in the figures.

The foregoing descriptions of specific exemplary embodiments of the present invention have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed, and obviously many modifications and variations are possible in light of the above teachings. The exemplary embodiments were chosen and described in order to explain certain principles of the invention and their practical application, to thereby enable others skilled in the art to make and utilize various exemplary embodiments of the present invention, as well as various alternatives and modifications thereof. It is intended that the scope of the invention be defined by the Claims appended hereto and their equivalents.

What is claimed is:

1. A method comprising:

at an imaging device comprising one or more light source sets, a detector and a controller, wherein at least one program is non-transiently stored in the controller and executable by the controller, the at least one program causing the controller to perform the method of:

(A) acquiring a reference image of a region of interest (ROI) by using the detector to collect light over a reference time period while the ROI is not exposed to any light emitted from the one or more light source sets, wherein the reference image comprises an array of pixels each corresponding to a sub-region in an array of sub-regions of the ROI;

(B) firing a first light source set while not firing any other light source set in the one or more light source sets, wherein the first light source set in the one or more light source sets emits light that is substantially limited to a first spectral range;

(C) acquiring a first target image of the ROI by using the detector to collect light over a first time period while the ROI is exposed to the light emitted from the first light source set, wherein the first target image comprises an array of pixels each corresponding to a sub-region in the array of sub-regions of the ROI; and

(D) compensating the first target image of the ROI using the reference image of the ROI, thereby generating a first compensated image of the ROI, wherein each respective pixel in the array of pixels of the first target image is compensated using the corresponding pixel in the array of pixels of the reference image.

2. The method of claim 1, wherein each respective pixel in the array of pixels of the first target image is compensated by subtracting, from an intensity value at the respective pixel, an intensity value at the corresponding pixel in the array of pixels of the reference image multiplied by a ratio of the first time period over the reference time period.

3. The method of claim 1, wherein the first time period is substantially the same as the reference time period.

4. The method of claim 1, wherein the first time period is between 1 millisecond and 100 milliseconds.

5. The method of claim 1, wherein the detector comprises a two-dimensional pixelated detector.

6. The method of claim 1, wherein the imaging device further comprises an objective lens in optical communication with the detector, wherein the first light source set in the one or more light source sets comprises a plurality of lighting components that is radially distributed about the objective lens.

7. The method of claim 1, wherein the light emitted from each light source set in the one or more light source sets has an intensity higher than the light from an ambient.

8. The method of claim 1, further comprising:

(E) co-registering, prior to the compensating (D), the reference image and the first target image of the ROI.

9. The method of claim 1, further comprising:

(F) firing a second light source set while not firing any other light source set in the one or more light source sets, wherein the second light source set in the one or more light source sets emits light that is substantially limited to a second spectral range, and the second spectral range that is different than the first spectral range;

(G) acquiring a second target image of the ROI by using the detector to collect light over a second time period while the ROI is exposed to the light emitted from the second light source set, wherein the second target image comprises an array of pixels each corresponding to a sub-region in the array of sub-regions of the ROI; and

(H) compensating the second target image of the ROI using the reference image of the ROI, thereby generating a second compensated image of the ROI, wherein each respective pixel in the array of pixels of the second target image is compensated using the corresponding pixel in the array of pixels of the reference image.

10. The method of claim 9, wherein each respective pixel in the array of pixels of the second target image is compensated by subtracting, from an intensity value at the respective pixel, an intensity value at the corresponding pixel in the array of pixels of the reference image multiplied by a ratio of the second time period over the reference time period.

11. The method of claim 9, wherein the second time period is substantially the same as the first time period and/or the reference time period.

12. A method comprising:

at an image device comprising a detector, a controller, and J light source sets for emitting light of K spectral ranges, wherein each spectral range is different than any other spectral range in the K spectral ranges, wherein for each respective k^{th} spectral range in the K spectral ranges, the J light source sets comprise corresponding j_k light source set or sets, wherein j_k is a positive integer of one or greater, and $\Sigma_{k=1}^{K} j_k = J$, and wherein at least one program is non-transiently stored in the controller and executable by the controller, the at least one program causing the controller to perform the method of:

(A) acquiring a reference image of a region of interest (ROI) by using the detector to collect light over a reference time period while the ROI is not exposed to any light emitted from the one or more light source sets, wherein the reference image comprises an array of pixels each corresponding to a sub-region in an array of sub-regions of the ROI; and

for each integer $k \in \{1, \ldots, K\}$:

(B) concurrently firing lighting components of the j_k light source set or sets in the J light source sets while not firing any other light source set in the J light source sets;

(C) acquiring a respectively target image of the ROI by using the detector to collect light over a respective k^{th} target time period while the ROI is exposed to the light emitted from the j_k light source set or sets, wherein the respective target image comprises an array of pixels each corresponding to a sub-region in the array of sub-regions of the ROI; and

(D) compensating the respective target image of the ROI using the reference image of the ROI, thereby generating a respective compensated image of the ROI, wherein each respective pixel in the array of pixels of the respective target image is compensated using the corresponding pixel in the array of pixels of the reference image.

13. The method of claim 12, wherein each respective pixel in the array of pixels of the respective target image is compensated by subtracting, from an intensity value at the respective pixel, an intensity value at the corresponding pixel in the array of pixels of the reference image multiplied by a ratio of the respective k^{th} target time period over the reference time period.

14. The method of claim 12, further comprising:

(E) co-registering, prior to the compensating (D), the reference image and the respective target image of the ROI.

15. The method of claim 12, further comprising:

(F) combining each respective compensated image of the ROI generated using each respective light source set in the plurality of light source sets into a single hyperspectral/multispectral image.

16. The method of claim 12, wherein J is a positive integer of three or greater and K is a positive integer smaller than J.

17. The method of claim 16, wherein:

two or more light source sets in the J light source sets emit light that is substantially limited to a first spectral range, and

one or more light source sets in the J light source sets emit light that is substantially limited to a second spectral range other than the first spectral range.

18. The method of claim 17, wherein:

one or more light source sets in the J light source sets emit light that is substantially limited to a third spectral range other than the first and second spectral ranges.

19. A non-transitory computer readable storage medium comprising instructions for use at an imaging device, wherein the imaging device comprises one or more light source sets, a detector and a controller, and the instructions

are non-transiently stored in the controller and executable by the controller, the instructions causing the controller to perform a method of:

(A) acquiring a reference image of a region of interest (ROI) by using the detector to collect light over a reference time period while the ROI is not exposed to any light emitted from the one or more light source sets, wherein the reference image comprises an array of pixels each corresponding to a sub-region in an array of sub-regions of the ROI;

(B) firing a first light source set while not firing any other light source set in the one or more light source sets, wherein the first light source set in the one or more light source sets emits light that is substantially limited to a first spectral range;

(C) acquiring a first target image of the ROI by using the detector to collect light over a first time period while the ROI is exposed to the light emitted from the first light source set, wherein the first target image comprises an array of pixels each corresponding to a sub-region in the array of sub-regions of the ROI; and

(D) compensating the first target image of the ROI using the reference image of the ROI, thereby generating a first compensated image of the ROI, wherein each respective pixel in the array of pixels of the first target image is compensated using the corresponding pixel in the array of pixels of the reference image.

20. A non-transitory computer readable storage medium comprising instructions for use at an imaging device, wherein the imaging device comprises a detector, a controller, and J light source sets for emitting light of K spectral ranges, wherein each spectral range is different than any other spectral range in the K spectral ranges, wherein for each respective k^{th} spectral range in the K spectral ranges, the J light source sets comprise corresponding j_k light source set or sets, wherein j_k is a positive integer of one or greater, and $\Sigma_{k=1}^{K} j=J$, and the instructions are non-transiently stored in the controller and executable by the controller, the instructions causing the controller to perform a method of:

(A) acquiring a reference image of a region of interest (ROI) by using the detector to collect light over a reference time period while the ROI is not exposed to any light emitted from the one or more light source sets, wherein the reference image comprises an array of pixels each corresponding to a sub-region in an array of sub-regions of the ROI; and

for each integer $k \in \{1, \ldots, K\}$:

(B) concurrently firing lighting components of the j_k light source set or sets in the J light source sets while not firing any other light source set in the J light source sets;

(C) acquiring a respectively target image of the ROI by using the detector to collect light over a respective k^{th} target time period while the ROI is exposed to the light emitted from the j_k light source set or sets, wherein the respective target image comprises an array of pixels each corresponding to a sub-region in the array of sub-regions of the ROI; and

(D) compensating the respective target image of the ROI using the reference image of the ROI, thereby generating a respective compensated image of the ROI, wherein each respective pixel in the array of pixels of the respective target image is compensated using the corresponding pixel in the array of pixels of the reference image.

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